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EISI ENGINEERING
INFORMATION
SYSTEMS, INC.

5120 CAMPBELL AVENUE, SUITE 240
SAN JOSE, CALIFORNIA 95130



NF01422

January 14, 1982

National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Huntsville, AL 35812

Attention: Mr. L. A. Kiefling, ED23

Subject: NAS8-32664 Final Report

Gentlemen:

This letter, together with the three enclosed reports, comprise the final report for the subject contract.

The enclosed reports, which were transmitted individually to MSFC in 3/80, 2/81, and 12/81, describe in detail the software developed under the contract and delivered to MSFC.

Sincerely,
Engineering Information Systems, Inc.

W. D. Whetstone
President



Enclosures:

- 1- SPAR Reference Manual Update, Revision 4 to EISI/A2200, 3/80
- 2- Procedures for Cyclically Symmetrical Structures, EISI TR 4012.80-1, 2/81
- 3- Macroelement Procedures, EISI TR 4012.60-1, 12/81

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N82-17520 #

MARCH 1980

Revision 4 to:
EISI/A2200

SPAR Reference Manual Update

SPAR Level 15

Prepared Under
NASA/MSFC Contract NAS8-32664

by

W. D. Whetstone

EISI

ENGINEERING INFORMATION SYSTEMS, INC

Suite 240 • 5120 Campbell Ave. • San Jose, CA 95130

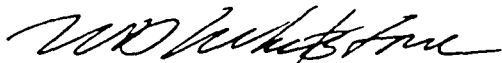
PREFACE

This document was prepared by Engineering Information Systems, Inc., for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration, under contract NAS8-32664. The Contracting Officer's Technical Representative was Mr. L. A. Kiefling.

The enclosed subsections and individual pages replace the corresponding portions of the preceeding version of the SPAR Reference Manual.

Submitted by:

Engineering Information Systems, Inc.



W. D. Whetstone
President

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- 14 SM- SYSTEM MODIFICATION PROCESSOR

TABLE 1-1: SPAR Element Repertoire.

| Name | Description | See Volume 1 Sections: |
|------|---|---------------------------|
| E21 | General straight or curved beam elements, e.g. channels, wide-flanges, angles, tubes, zees. | 3.1.7 - 9 |
| E22 | Beams for which the intrinsic stiffness matrix is given. | 3.1.10 |
| E23 | Bar - Axial stiffness only. | 3.1.11 |
| E24 | Plane beam. | 3.1.12 |
| E25 | Zero-length element used to elastically connect geometrically coincident joints. | 3.1.10 |
| | Two-dimensional (area) elements: | 3.1.13 |
| E31 | Triangular membrane. | |
| E32 | Triangular plate. | |
| E33 | Triangular combined membrane and bending element. | |
| E41 | Quadrilateral membrane. | |
| E42 | Quadrilateral plate. | |
| E43 | Quadrilateral combined membrane and bending element. | |
| E44 | Quadrilateral shear panel. | 3.1.14 |
| | Three-dimensional solids: | 3.2.2.3 |
| S41 | Tetrahedron (pyramid). | |
| S61 | Pentahedron (wedge). | |
| S81 | Hexahedron (brick). | |
| | Compressible fluid elements: | 12., 3.2.2.3 |
| F41 | Tetrahedron (pyramid). | |
| F61 | Pentahedron (wedge). | |
| F81 | Hexahedron (brick). | |

Notes:

- See Section 7.2 for examples of stress output.
- See Volume 2 (Theory) for element formulation details.
- Anisotropic constitutive relations permitted, all area elements.
- Laminated cross sections permitted for E33, E43.
- Membrane/bending coupling permitted for E33, E43.
- E41, E42, E43, E44 may be warped.
- Anisotropic constitutive relations permitted for 3-D solids.
- Non-structural mass permitted for line and area elements.

3.1.9 E21 SECTION PROPERTIES (BA)

Element type E21 is a general family of either straight or curved beam elements. E21 element formulation details are discussed in Section A of Volume 2.

BA is used to create tables of E21 section properties. When E21 elements are defined using processor ELD, references to entries in this table are made using the NSECT table pointer.

Nine different types of cross-section input are provided. The first word in each input record identifies the cross-section type, e.g. TUBE. A single input record defines one section, except for section type DSY, which requires two records. Data sequences for individual types of cross-sections are indicated below.

| | |
|------|--|
| BOX | k, b_1, t_1, b_2, t_2 |
| TEE | k, b_1, t_1, b_2, t_2 |
| ANG | k, b_1, t_1, b_2, t_2 |
| WFL | k, $b_1, t_1, b_2, t_2, b_3, t_3$ |
| CHN | k, $b_1, t_1, b_2, t_2, b_3, t_3$ |
| ZEE | k, $b_1, t_1, b_2, t_2, b_3, t_3$ |
| TUBE | k, inner radius, outer radius |
| GIVN | k, $I_1, \alpha_1, I_2, \alpha_2, a_c, f, f_1, z_1, z_2, \theta$ |
| DSY | k, $I_1, \alpha_1, I_2, \alpha_2, a_c, f, f_1$ (card 1) |
| | $q_1, q_2, q_3, y_{11}, y_{12}, \dots, y_{41}, y_{42}$ (card 2) |

In the above, k identifies the table entry number. The b's and t's are cross-section dimensions defined on Figure BA-1. In all cases the origin and terminus of the beam (see discussions of MREF, BRL, and ELD) coincide with the section centroid. For GIVN and DSY sections,

I_1, I_2 Principal moments of inertia. For DSY sections, principal axes must coincide with the element reference frame axes.

α_1, α_2 Transverse shear deflection constants associated with I_1 and I_2 , respectively. For no shear deflection, set α_1 equal to zero.

a_c Cross-sectional area.

Circled numbers identify locations where bending stresses are evaluated.

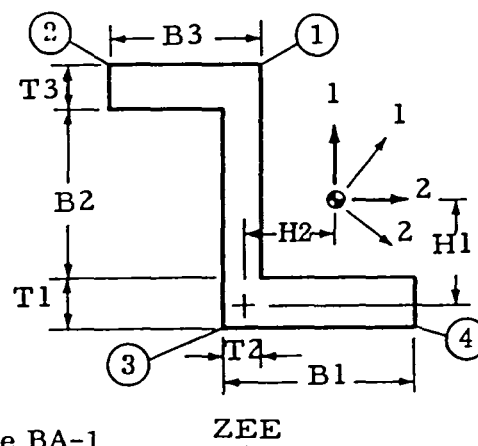
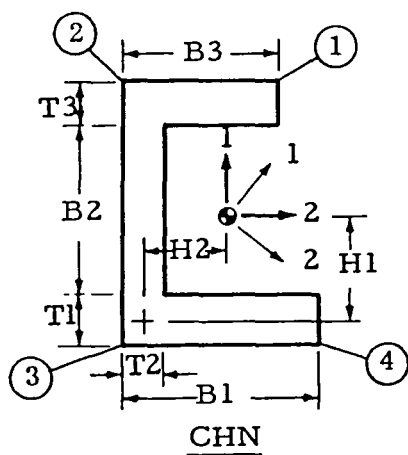
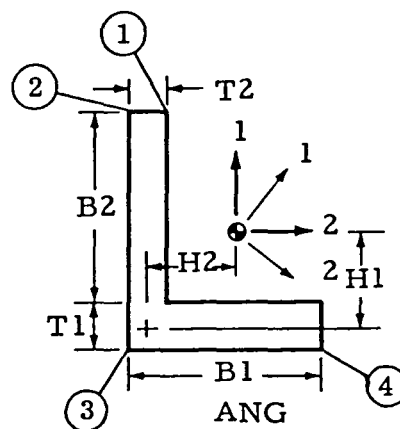
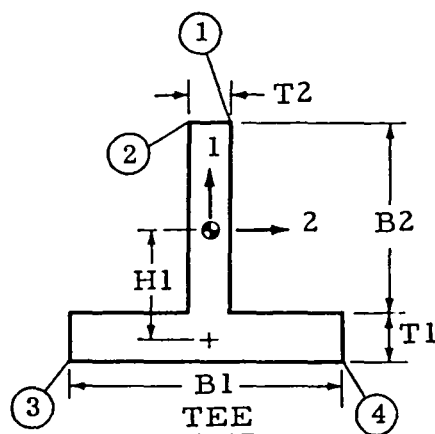
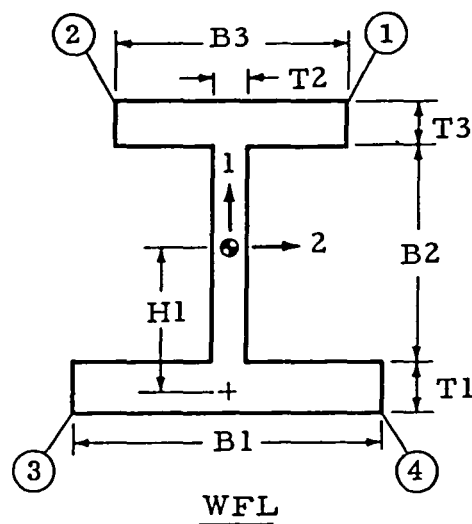
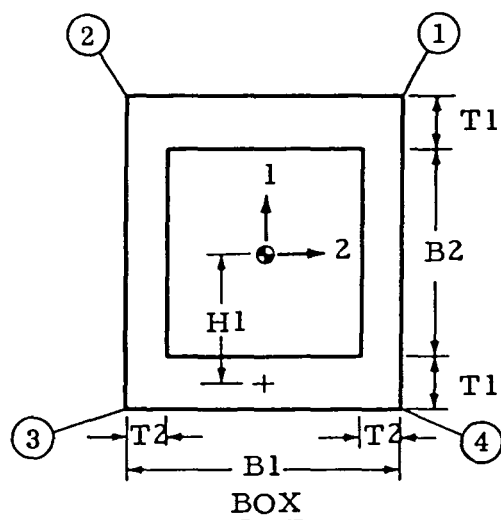
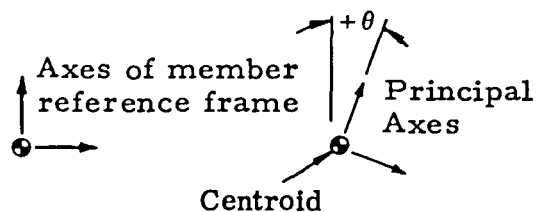


Figure BA-1

- f Uniform torsion constant.* For uniform torsion, torque = $Gf \times (\text{twist angle/unit length})$, where G is the shear modulus.
- f_1 Nonuniform torsion constant*, accounting for flange-bending effects on torsional stiffness, etc.
- z_1, z_2 Shear center - centroid offsets.
- θ Inclination of principal axes relative to the element reference frame (see Figure BA-1). θ is in radians.

Use of section properties in computing element stiffness matrices is discussed in Volume 2. Items on the second card defining DSY sections are used by the program to compute stresses, as indicated below:

S1= $V_1 q_1$ = Transverse shear stress, direction 1.

S2= $V_2 q_2$ = Transverse shear stress, direction 2.

TWIST= $T q_3$ = Twisting shear stress.

Combined axial+
bending stress
at point i=

$$P/a_c + M_2 Y_{i1}/I_2 - M_1 Y_{i2}/I_1$$

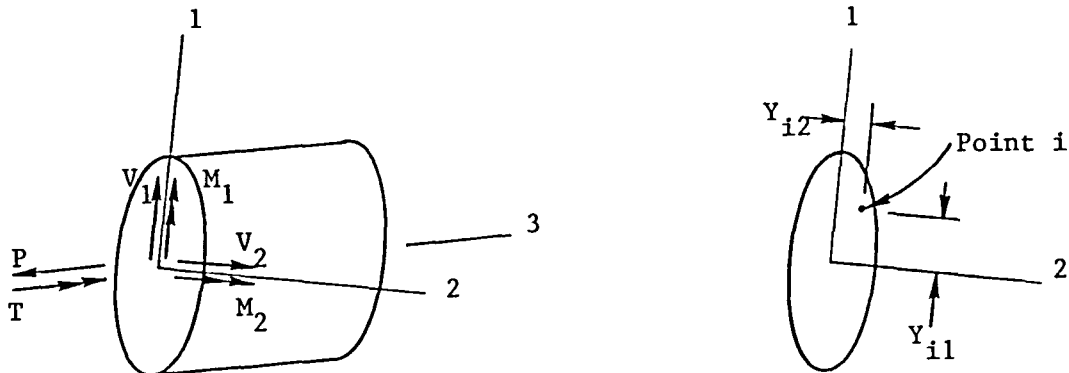


Figure BA-2

Combined stresses for curved beams may be computed by an alternate method which is discussed subsequently.

*In the notation of Volume 2, Section A,

$$C = Gf, \text{ and}$$

$$C_1 = Ef_1$$

Curved Beams. E21 elements having DSY type cross-sections may be circularly curved, as shown on Figure BA-3. Ordinary curved beam theory,¹ extended to include transverse shear deformation and torsion, is used to construct the elastic stiffness matrices of curved beams. The centerline of a curved E21 element lies in the element 1/3 plane, as shown on Figure BA-3, so that I_2 and α_2 establish flexural stiffness characteristics for bending in the plane of initial curvature. The input convention for curved beams is intended to give the user the opportunity to choose the basis of (1) reducing effective moments of inertia, and (2) stress recovery coefficients. The user must make any adjustments to I_2 necessary to account for reduced bending stiffness due to cross-section flattening.

The following commands are used to define curved beam attributes:

| <u>Command</u> | <u>Default Value</u> | <u>Meaning</u> |
|----------------|----------------------|---|
| R= r\$ | none | Radius - see Figure BA-3. |
| E= e\$ | .0 | Centroid-neutral axis eccentricity ¹ Also see the subsequent discussion of stresses. |
| C= c\$ | 1.0 | See subsequent discussion of stresses. |

When any of the above commands is given, the indicated attribute will apply to all DSY sections subsequently defined, until the attribute is redefined by another command. To indicate that subsequent sections are for straight beams, give the command STRAIGHT.

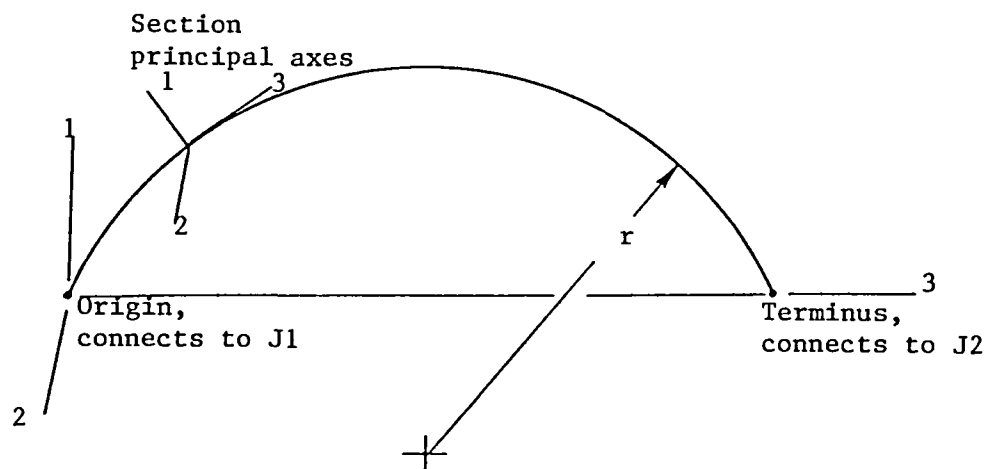


Figure BA-3

¹Timoshenko, S. P., "Strength of Materials, Part 1", Ch. 12, pp 362-416. See the discussion at the end of this section concerning M and KG matrices.

Computation of flexural stresses in curved beams is based on the input values of r , e , and c , and the y_{ij} 's given on the second card defining the DSY section properties, as follows:

For point i , the combined direct + flexural stress, s_i , is:

$$s_i = \frac{P}{a_c} + c \frac{M_2}{a_c e} \frac{(Y_{i1} + e)}{(Y_{i1} + r)} - \frac{M_1 Y_{i2}}{I_1} ,$$

unless $e = .0$, in which case

$$s_i = \frac{P}{a_c} + \frac{M_2 Y_{i1}}{I_2} - \frac{M_1 Y_{i2}}{I_1} .$$

M and KG terms associated with curved beams are handled as follows:

- In computing both consistent and diagonal system mass matrices, contributions of curved beams consist of two equal masses lumped at the connected joints.
- In KG , geometric stiffness matrix terms are computed as though the beam were straight.

6.1.6.1 Temperatures. The content of each entry (data column) within a TEMP E1j iset icase data set is described in this section.

- For E21, E22, E23, and E24 elements, each entry contains the following three words:

$$T_a, T'_1, T'_2$$

T_a is the average temperature of the element, and T'_1 and T'_2 are temperature gradients in directions 1 and 2, respectively, of the element reference frame.

In the following, T_{j1} and T_{j2} are the nodal temperatures of joints j1 and j2 from block icase of NODAL TEMP iset, if present.

The system assumes that the temperature along the element centerline is a constant, T , where

$$T = T_a + \frac{1}{2}(T_{j1} + T_{j2}).$$

If a rigid link connects joint j1 to the element origin, the temperature of the link is assumed to be a constant, T_{r1} , where

$$T_{r1} = T_{j1} + T_a$$

If a rigid link connects joint j2 to the terminus, the temperature of the link is assumed to be a constant, T_{r2} , where

$$T_{r2} = T_{j2} + T_a$$

The gradients, T'_1 and T'_2 apply only to the elastic part of the element, not to the rigid links. The rigid links are assumed to have the same thermal expansion coefficient as the elastic part of the element.

Example. Case 5 and 7 of set 48, type E21 elements.

@XQT AUS

-

-

ELDATA: TEMP E21 48

CASE 5

G=4: E= 10, 20\$

Elements 10 through 20 of group 4.

100., 10., 20.\$

$T_a = 100.$, $T'_1 = 10.$, $T'_2 = 20.$

CASE 7

G=4: E=50\$

Element 50 of group 4.

22., 1.5, 2.7\$

$T_a = 22.$, $T'_1 = 1.5$, $T'_2 = 2.7.$

I=1\$

Following data records contain T_a only.

G=4: E= 1, 5\$

1.2, 1.3, 1.4, 1.5, 1.6\$

T_a 's for elements 1-5 of group 4.

6.1.6.2 Dislocations (initial strains). Dislocational loading, which is similar to thermal loading, is used to describe situations in which element strains are not zero in the null structure. The term "null structure" indicates the state in which all joints are held motionless. Dislocations are the deformations an element would undergo if disconnected from the null structure, allowing it to assume a strain-free state.

The content of each entry (data column) within a DISL Eij iset icase data set is described below.

- For E21, E22, E23, E24, and E25 elements, each entry contains six words:

$$d_1, d_2, d_3, r_1, r_2, r_3$$

These quantities have the following interpretation. the d's and r's are displacements and rotations of the origin, relative to a reference frame, parallel to the member reference frame, embedded in the terminus.

For example, thermal (TEMP) loading defined for a straight E21 element of length ℓ could also be modeled as dislocational (DISL) loading if the following values of the d's and r's were used:

$$d_1 = -\alpha T_1' \frac{\ell^2}{2} \quad , \quad d_2 = -\alpha T_2' \frac{\ell^2}{2} \quad , \quad d_3 = -\alpha T_a \ell$$

$$r_1 = -\alpha T_2' \ell \quad , \quad r_2 = \alpha T_1' \ell \quad , \quad r_3 = 0.$$

Example Input. Case 7 of set 4, E21 elements:

@XQT AUS

ELDATA: DISL E21 4

CASE 7

| | |
|---------------------------------|--------------------------------|
| G= 3: E= 7\$ | Element 7 of group 3. |
| 1.2, 1.5, 1.1, .01, .017, .18\$ | $d_1, d_2, d_3, r_1, r_2, r_3$ |
| I= 1, 3, 6\$ | Identify d_1, d_3, r_3 |
| G= 4: E= 2, 3\$ | |
| 1.1, 4.2, .00817\$ | Element 2, group 4. |
| 3.2, 6.7, .00903\$ | Element 3, group 4. |

Section 10

GRAPHICS

There are three graphics processors: PLTA, PLTB, and PXY. PLTA (Section 10.1) is a pre-processor for PLTB (Section 10.2) as shown on Figure 10-1. PXY, which is used independently, is described in Section 10.4. It is suggested that the new user examine the examples shown in Section 10.3 before reading 10.1 and 10.2.

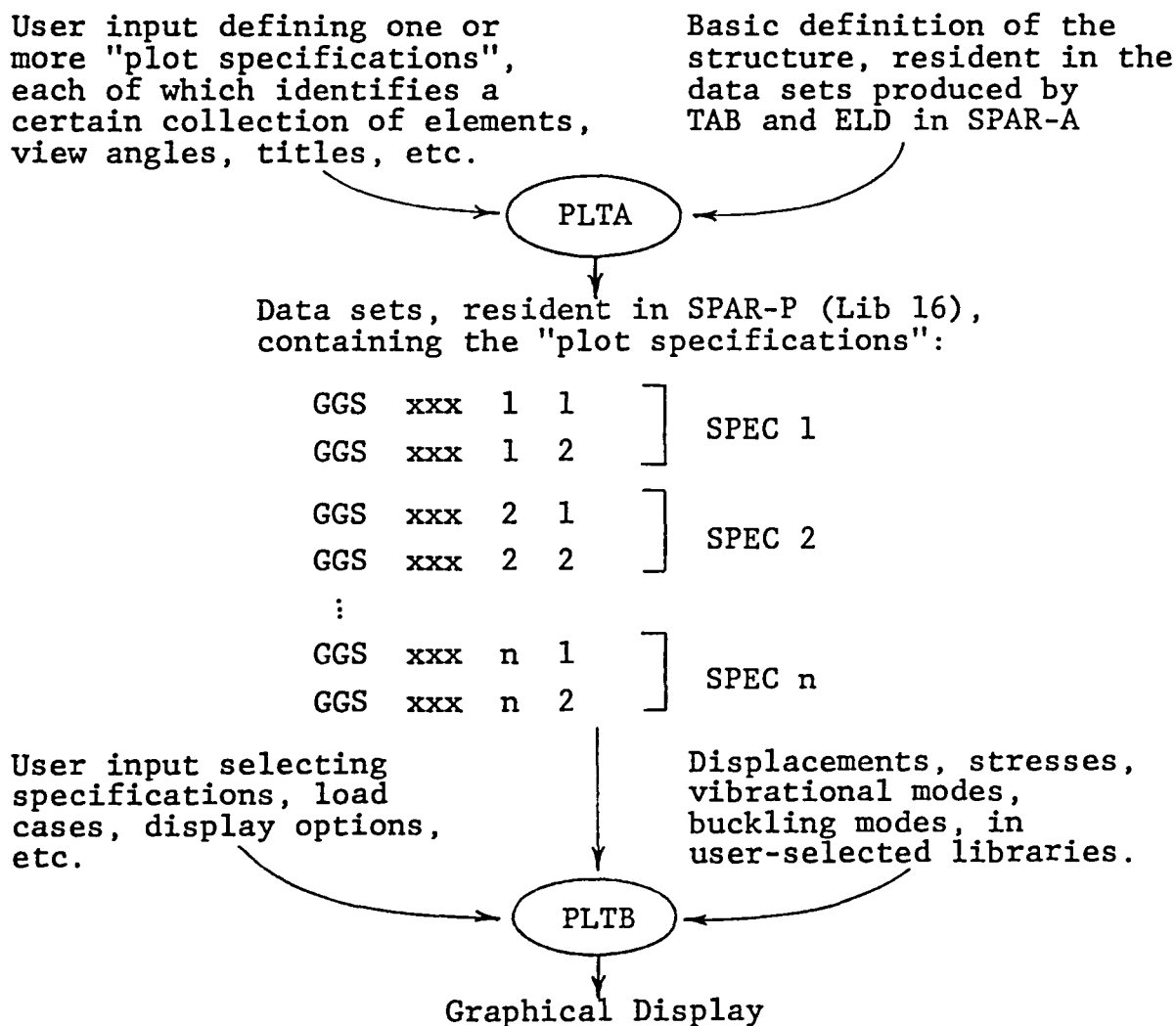


Fig. 10-1 PLTA - PLTB Data Exchange

10.3 EXAMPLES OF PLTA - PLTB EXECUTIONS

The examples on the following pages illustrate PLTA and PLTB command sequences used to produce typical kinds of graphical displays.

10.4 PXY - GENERAL PURPOSE GRAPHIC DISPLAY GENERATOR

10.4.1 Introduction and Command Summary. PXY is a general purpose processor for producing graphical displays. The user may compose very general forms of display of data which has previously been stored in data sets. One application is the production of x-y plots of transient response data. PXY commands fall in three categories:

Category 1: Through these preliminary commands, the user establishes the values of control parameters which determine the configuration and attributes of graphical displays which are subsequently produced as a result of Category 3 commands. Typical Category 1 commands establish the position of the plot on the screen, establish whether or not axes will be drawn, control axis tic-mark spacing, tic-mark numerals, and labelling, optionally establish manual or automatic scaling, select fonts, etc.

Category 2: These commands identify source data sets containing information to be displayed as a result of subsequent Category 3 commands.

Category 3: These commands cause curves, symbols, and/or alphanumeric text to be plotted.

The following is a summary of all the PXY commands, including alternate forms. Details are given in Section 10.4.2.

| <u>Section Reference</u> | <u>Figure Reference</u> | <u>Category 1, Preliminary Commands:</u> |
|--------------------------|-------------------------|--|
| 10.4.2.1 | 10.4-1 | BOUNDARIES= h1, h2, v1, v2 |
| 10.4.2.2 | 10.4-1 | XAXIS= NONE |
| " | " | XAXIS= ndigits, dxtic, mintics, maxtics |
| " | " | XAXIS= ndigits, mintics, maxtics |
| " | " | YAXIS= NONE |
| " | " | YAXIS= ndigits, dytic, mintics, maxtics |
| " | " | YAXIS= ndigits, mintics, maxtics |
| 10.4.2.3 | " | XLABEL' alphanumeric X axis label |
| " | " | YLABEL' alphanumeric Y axis label |
| " | " | |
| 10.4.2.4 | | XLIMITS= NONE |
| " | | XLIMITS= xleft, xright |
| " | | YLIMITS= NONE |
| " | | YLIMITS= ybottom, ytop |

| <u>Section Reference</u> | <u>Category 1, Preliminary Commands (continued):</u> |
|-----------------------------------|--|
| 10.4.2.5 " | XYSCALE= AUTOMATIC XYSCALE= rxy |
| 10.4.2.6 " " " " " | FONT XNUMBERS= nfont FONT YNUMBERS= nfont FONT XLABEL= nfont FONT YLABEL= nfont FONT TEXT= nfont FONT SYMBOL= nfont |
| 10.4.2.9 | RETAIN |
| 10.4.2.12 | TPOSITION |

| <u>Section Reference</u> | <u>Category 2, Commands Which Identify Source Data Sets:</u> |
|------------------------------|---|
| 10.4.2.7 " " | X= Lib N1 N2 n3 n4 Y= Lib N1 N2 n3 n4 TEXT= Lib N1 N2 n3 n4 |

| <u>Section Reference</u> | <u>Figure Reference</u> | <u>Category 3, Commands Which Cause Plots to be Displayed:</u> |
|------------------------------|-----------------------------|--|
| 10.4.2.8 " | | FLUSH ADVANCE or CLEAR |
| 10.4.2.9 | 10.4-1 | INITIALIZE |
| 10.4.2.10 " | 10.4-2 " | PLOT CURVE PLOT CURVE # n |
| 10.4.2.11 " | | PLOT CONSTANT X= x1, x2, x3, - - - PLOT CONSTANT Y= y1, y2, y3, - - - |
| 10.4.2.12 | 10.4-3 | PLOT TEXT |

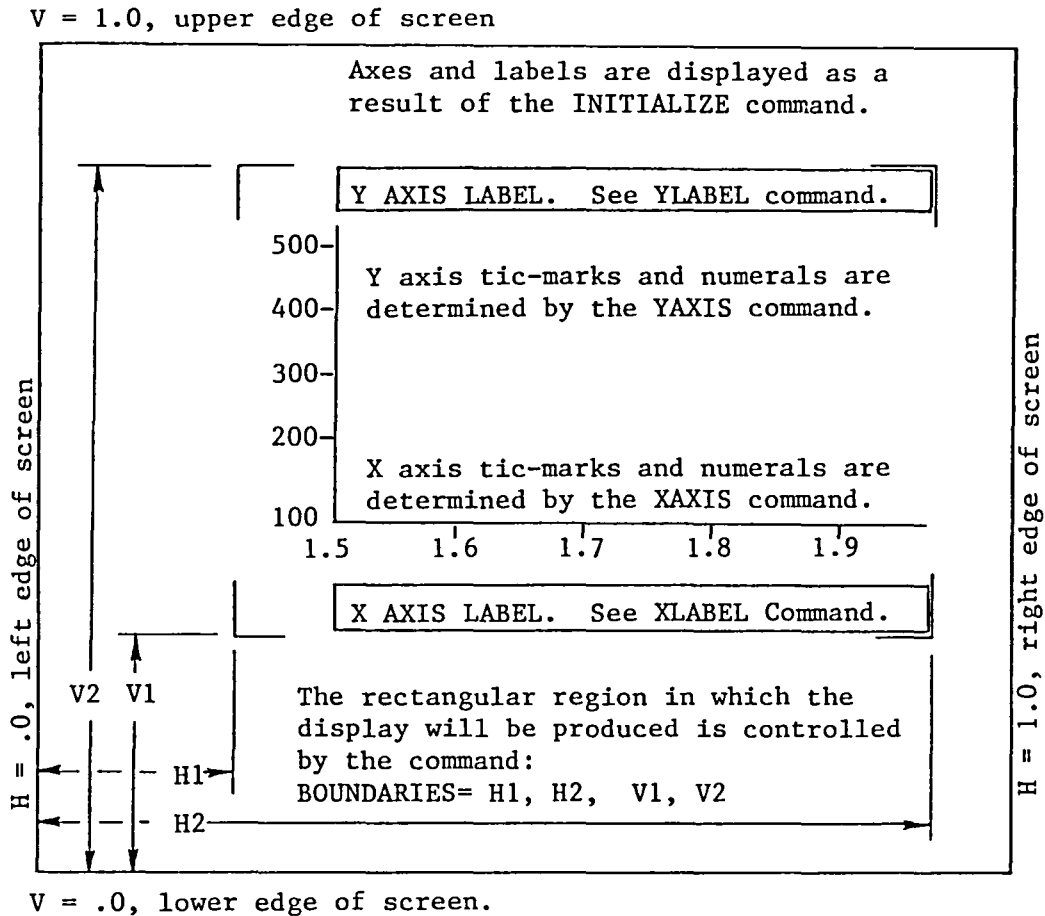


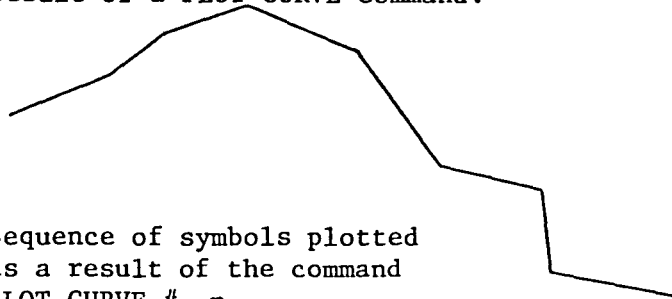
Figure 10.4-1: POSITIONING OF DISPLAYS, AND GRID CONFIGURATION.

The BOUNDARIES command may be used repeatedly to reposition the rectangular region within which curves and/or alphanumeric text are to be plotted using the PLOT commands illustrated on Figures 10.4-2 and 10.4-3. The axes and labels shown on Figure 10.4-1 need not be displayed unless required.

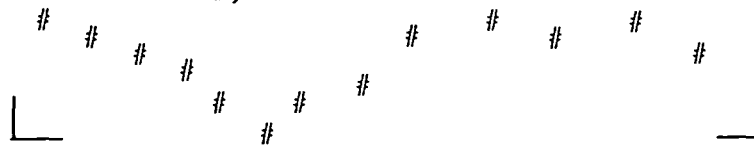
Scaling may be controlled directly through the XLIMIT, YLIMIT and XYSIZE commands, or the program will automatically determine scales based on the content of the arrays to be plotted.

An example is given in Section 10.4.6.

Sequence of line segments displayed as a
result of a PLOT CURVE command:



Sequence of symbols plotted
as a result of the command
PLOT CURVE #, n



Alphanumeric text displayed as
a result of a PLOT TEXT
command.

10.4.2 Command Rules.

Details of all PXY commands are explained in the following subsections.

10.4.2.1 BOUNDARIES. The form of this command is:

BOUNDARIES= h1, h2, v1, v2

As illustrated on Figure 10.4-1, this command establishes the boundaries of a rectangular region on the screen within which curves, symbols, or alphanumeric text will be plotted as a result of subsequent commands. It is mandatory that

$$\begin{aligned} &.0 \leq h1 < h2 \leq 1.0, \text{ and} \\ &.0 \leq v1 < v2 \leq 1.0 \end{aligned}$$

The default is a full screen display, BOUNDARIES= .0, 1., .0, 1.

10.4.2.2 XAXIS and YAXIS. The XAXIS command controls the following (see Figure 10.4-2):

- whether or not the X axis will be displayed,
- X axis tic-mark spacing, if any, and
- the number of digits in the X axis tic-mark numerals, if any.

Three forms of the XAXIS command are permitted. If you do not want the X axis and associated tic-marks and tic-mark numerals to be displayed, the command XAXIS=NONE must be given.

In the following two forms of the XAXIS command, ndigits is the number of digits in the tic-mark numerals, mintics is the minimum number of tic-marks, and maxtics is the maximum number of tic-marks. To eliminate the numerals, set ndigits=0. To eliminate the tic-marks, set mintics=0 and maxtics=0.

If you want tic-marks to appear at equal intervals of dxtic, give the following command:

XAXIS= ndigits, dxtics, mintics, maxtics

If you wish to have tic-mark spacing determined automatically, give the following command:

XAXIS= ndigits, mintics, maxtics

The default is XAXIS= 2, 2, 5 (i.e. ndigits=2, mintics=2, and maxtics=5).

For the Y axis, the YAXIS command serves the same function as described above for the X axis.

10.4.2.3 XLABEL and YLABEL. Through these commands the user furnishes alphanumeric labels for the X and Y axes, to be positioned as shown on Figure 10.4-1. The commands are:

XLABEL' Text of alphanumeric label for the X axis.
YLABEL' Text of alphanumeric label for the Y axis.

If either command is omitted, the corresponding label will be omitted. If the label is too long to fit in the available space, it will be truncated.

The axis labels will not be displayed until the INITIALIZE command is given. See Section 10.4.2.9.

10.4.2.4 XLIMITS and YLIMITS. These commands control the values of x and y at the edges of the plot. By the "edges" of the plot, we mean the edges of the subspace remaining within the rectangular region defined by the BOUNDARIES command, reduced as necessary to accommodate the axes, tic-mark numerals, and labels, if present.

In the following, xleft and xright are the values of x at the edges of the plot, and ybottom and ytop are the edge values of y. To directly define the edge values of x and y, use the following commands:

XLIMITS= xleft, xright
YLIMITS= ybottom, ytop

To permit PXY to automatically determine the edge values based on the content of the X and Y arrays to be plotted, use the following commands:

XLIMITS= NONE
YLIMITS= NONE

The defaults are XLIMITS= NONE and YLIMITS= NONE.

10.4.2.5 XYSCALE. To cause the ratio of x scale to y scale to be rxy, give the following command:

XYSCALE= rxy

The XYSCALE command may cause adjustment to the plot edge coordinates as specified by XLIMIT and YLIMIT commands, if given, in order to keep the display within the available screen space. To revert to the default mode of operation of automatically determined x and y scaling, give the following command:

XYSCALE= AUTOMATIC

10.4.2.6 FONT. Depending upon the type of plotting device being used, and the host system graphics library, a variety of character fonts (size and shape) may be available. In the following commands, nfont is an integer designating a particular font. The default for all fonts is nfont= 1 (integer one). On systems where more than one font is available, successive values of nfont, i.e. 2, 3, - - - usually will indicate progressively larger character sizes. The commands are:

| <u>Command</u> | <u>Character Display Affected</u> |
|---------------------|---------------------------------------|
| FONT XNUMBERS=nfont | X axis tic-mark numbers |
| FONT YNUMBERS=nfont | Y axis tic-mark numbers |
| FONT XLABEL= nfont | X axis label |
| FONT YLABEL= nfont | Y axis label |
| FONT TEXT= nfont | Text plotted via PLOT TEXT |
| FONT SYMBOL= nfont | Characters plotted via PLOT CURVE # n |

10.4.2.7 X, Y, and TEXT. In the following commands, default values of Lib, N2, n3, and n4 are 1, MASK, MASK, and MASK.

To identify a data set containing alphanumeric text to be displayed as a result of a subsequent PLOT TEXT command, give the following command:

TEXT= Lib N1 N2 n3 n4

To identify data sets containing x and y values to be plotted by subsequent PLOT CURVE commands, give the following commands:

X= Lib N1 N2 n3 n4
Y= Lib N1 N2 n3 n4

It is mandatory that the TOC parameter NI=1 for both X and Y. It is permissible for X and Y to have different NJ's, in which case the smaller NJ will determine the number of points to be plotted.

10.4.2.8 FLUSH, and ADVANCE or CLEAR. If plotting on a CRT device for which the host system is buffering the output, the command FLUSH will cause the buffer to be flushed, completing the screen display.

Either of the synonymous commands, ADVANCE or CLEAR, will cause the screen to be cleared (or frame advanced).

10.4.2.9 INITIALIZE, and RETAIN. The command INITIALIZE must be given before any PLOT CURVE commands are given. In the default mode the INITIALIZE command causes two actions:

- 1- Scaling will be established, based on (a) the current values of all of the Category 1 commands, and (b) the contents of the currently defined X and Y arrays.
- 2- The X and Y axes, tic-marks, tic-mark numerals, and X and Y axis labels will be displayed, if requested through prior Category 1 commands.

To inhibit redefinition of scale factors upon execution of subsequent INITIALIZE commands, give the command RETAIN=ON . To resume the default mode in which each INITIALIZE command results in scale factor determination, give the command RETAIN=OFF .

10.4.2.10 PLOT CURVE. The command,

PLOT CURVE

causes a sequence of straight line segments to be drawn, as illustrated on Figure 10.4-2, connecting successive (x,y) points established by the contents of the data sets identified by the last X= and Y= commands.

To cause the character #, or any other designated character, to be plotted on every n-th (x,y) point pair, give the following command:

PLOT CURVE #, n

10.4.2.11 PLOT CONSTANT. To cause vertical lines to be drawn at x1, x2, - - -, give the following command:

PLOT CONSTANT X= x1, x2, - - -

To cause horizontal lines to be drawn at y1, y2, - - -, give the following command:

PLOT CONSTANT Y= y1, y2, - - -

10.4.2.12 PLOT TEXT and TPOSITION. To cause the alphanumeric text contained in the data set identified by the last TEXT command to be displayed as indicated on Figure 10.4-3, give the command:

PLOT TEXT

The position of the text within the space designated by the preceding BOUNDARIES command may be controlled by preceding the PLOT TEXT command with the command:

TPosition= plateral, pvertical

Plateral values of -1, 0, and +1 indicate left, center, and right positioning, in that order.

Pvertical values of -1, 0, and +1 indicate lower, center, and upper positioning, in that order.

The default is TPOSITION= 0, 0\$.

10.4.3 Error Messages.

The following is a summary of the error messages produced by PXY.

| <u>NERR</u> | <u>NIND</u> | <u>Command, Error</u> |
|-------------|-------------|---|
| EXPX | 301 | BOUNDARY, parameters not floating point number. |
| EXPX | 302 | " h2.LT.h1 |
| EXPX | 303 | " v2.LT.v1 |
| EXPX | 621 | XAXIS or YAXIS, ndigits not integer. |
| EXPX | 622 | " dxtic not floating point. |
| EXPX | 631 | " ndigits not integer. |
| EXPX | 632 | " mintics " " |
| EXPX | 633 | " maxtics " " |
| EXPX | 801 | XLIMITS or YLIMITS, syntax error. |
| EXPX | 811 | " xleft or ybottom not floating point. |
| EXPX | 812 | " xbottom or ytop " " " |
| EXPX | 1101 | XYSCALE, illegal syntax or rxy value. |
| EXPX | 1201 | TEXT, source data set unavailable. |
| EXPX | 1301 | TPOSITION, plateral not integer. |
| EXPX | 1302 | " pvertical " " |
| EXPX | 1401 | X or Y, source data set not available. |
| EXPX | 1601 | FONT, unknown font identifier. |
| EXPX | 3004 | INITIALIZE, FONT, illegal font code. |
| EXPX | 3101 | PLOT, Command syntax error. |
| EXPX | 3201 | PLOT CURVE, either X or Y not defined. |
| EXPX | 3202 | " " not preceded by INITIALIZE. |
| EXPX | 3204 | PLOT TEXT, FONT, illegal font code. |
| EXPX | 3205 | PLOT TEXT, POSITION, illegal plateral. |
| EXPX | 3206 | " " " pvertical. |
| EXPX | 3241 | PLOT CURVE # n, illegal font. |

| <u>NERR</u> | <u>NIND</u> | <u>Command, Error (continued)</u> |
|-------------|-------------|--|
| EXPX | 3301 | PLOT CONSTANT X or Y, no xi's or yi's. |
| EXPX | 3302 | " " illegal syntax. |
| EXPX | 3303 | " " some xi or yi not floating point. |
| EXPX | 10000 | Unrecognizable command. |

10.4.4 Reset Controls.

No special RESET controls are provided.

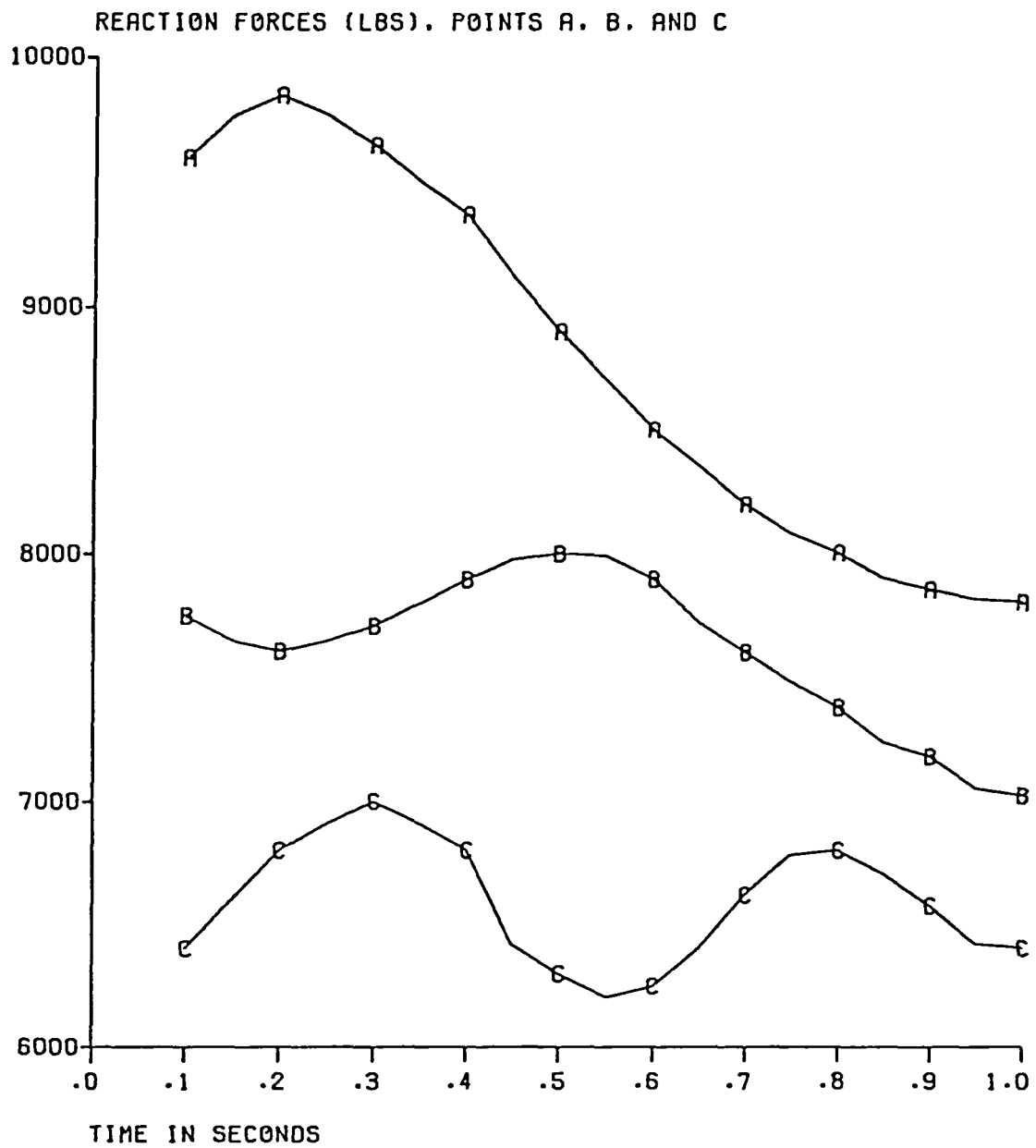
10.4.5 Central Memory Requirements.

PXY requires data space sufficient to simultaneously contain one block of each source data set currently being plotted, plus 1000 words.

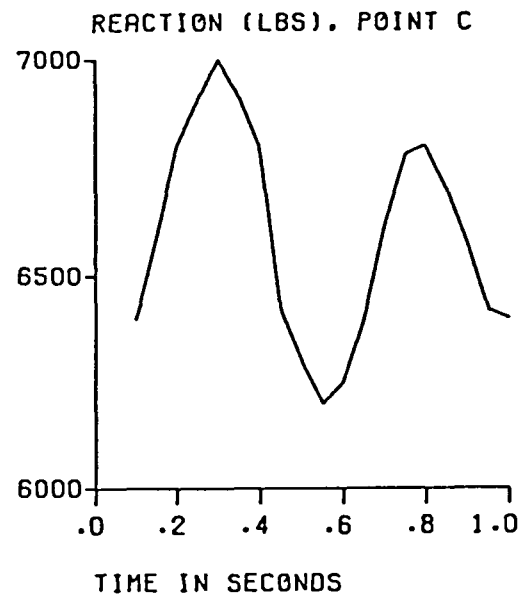
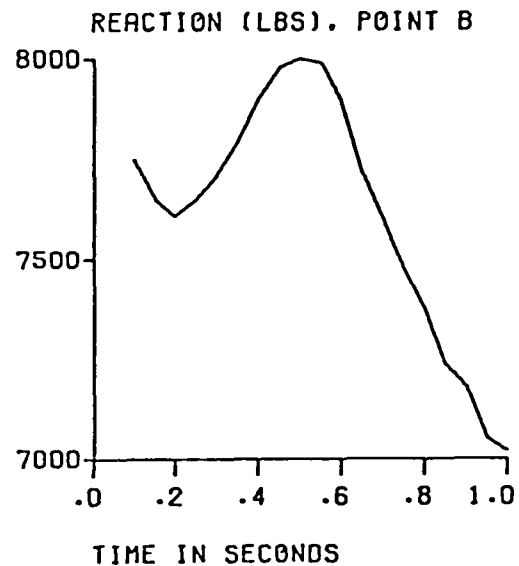
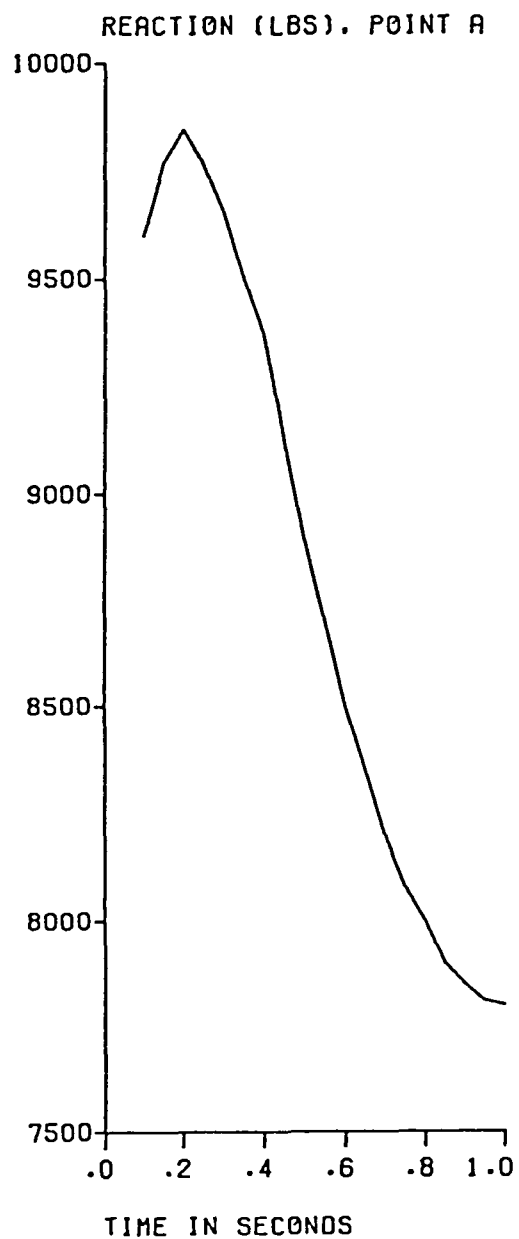
10.4.6 Example.

The following runstream was used to produce the plots shown on the next two pages.

```
@XQT AUS
$
$ CREATE DATA SETS NAMED TITLE, X, A, B, AND C TO BE USED AS
$ SOURCE DATA FOR THE EXAMPLE PXY DISPLAY:
$
ALPHA: TITLE: 1' RESPONSE TO BASE EXCITATION, CASE 407A
TABLE(NI=1,NJ=19): X: DDATA=.05: J=1,19: .1
TABLE(NI=1,NJ=19): A: J=1,19
9600. 9770. 9850. 9770. 9650. 9500. 9370. 9120. 8900. 8700.
8500. 8350. 8200. 8080. 8000. 7900. 7850. 7810. 7800.
TABLE(NI=1,NJ=19): B: J=1,19
7750. 7650. 7610. 7650. 7710. 7800. 7900. 7980. 8000. 7990.
7900. 7720. 7600. 7480. 7380. 7240. 7180. 7050. 7020.
TABLE(NI=1,NJ=19): C: J=1,19
6400. 6600. 6800. 6910. 7000. 6910. 6800. 6420. 6300. 6200.
6250. 6400. 6620. 6780. 6800. 6700. 6570. 6420. 6400.
$
@XQT PXY
$
$ CREATE A SINGLE FULL-PAGE PLOT WITH THREE CURVES ON ONE GRAPH:
$
ADVANCE
BOUNDARIES=.01 .99 .01 .2: TEXT=TITLE: PLOT TEXT
BOUNDARIES=.01 .99 .2 .99: XAXIS=1 .1 11 11: YAXIS=5 1000. 5 5
XLIMITS=0. 1.: YLIMITS=6000. 10000.
XLABEL='TIME IN SECONDS
YLABEL='REACTION FORCES (LBS), POINTS A, B, AND C
X=X: Y=A: INITIALIZE: PLOT CURVE: PLOT CURVE A 2
Y=B: PLOT CURVE: PLOT CURVE B 2
Y=C: PLOT CURVE: PLOT CURVE C 2
$ FIRST PLOT FRAME COMPLETED
$
$ BEGIN SECOND PLOT, WHICH WILL CONTAIN THREE SEPARATE GRAPHS:
$
ADVANCE
XLIMITS=0. 1.: YLIMITS=NONE: X=X: XLABEL='TIME IN SECONDS
BOUNDARIES=.01 .99 .01 .2: PLOT TEXT
BOUNDARIES=.01 .48 .2 .99: XAXIS=1 .2 2 6: YAXIS=5 500. 2 10
YLABEL='REACTION (LBS), POINT A
Y=A: INITIALIZE: PLOT CURVE
BOUNDARIES=.52 .99 .63 .99: YAXIS=4 500. 2 10
YLABEL='REACTION (LBS), POINT B
Y=B: INITIALIZE: PLOT CURVE
BOUNDARIES=.52 .99 .2 .58
YLABEL='REACTION (LBS), POINT C
Y=C: INITIALIZE: PLOT CURVE
$ SECOND PLOT FRAME COMPLETED
```

RESPONSE TO BASE EXCITATION, CASE 407A



RESPONSE TO BASE EXCITATION, CASE 407A

PROCEDURES FOR
CYCLICALLY SYMMETRICAL STRUCTURES

by
C. E. Jones

February 1981

EISI

ENGINEERING INFORMATION SYSTEMS, INC

Suite 240 • 5120 Campbell Ave. • San Jose, CA 95130

PREFACE

This report was prepared by Engineering Information Systems, Inc., for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration under contract NAS8-32664. The Contracting Officer's Technical Representative was Mr. L. A. Kiefling.

The cyclic symmetry procedures were designed jointly by W. D. Whetstone and C. E. Jones, and were prepared and tested by Dr. Jones.

Submitted by:

Engineering Information Systems, Inc.

A handwritten signature in dark ink, appearing to read "W. D. Whetstone". The signature is fluid and cursive, with the first letters of the first and last names being capitalized and prominent.

W. D. Whetstone
President

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1. INTRODUCTION

EAL command runstream elements are presented for analyzing structural systems that are composed of a number of cyclically symmetrical sectors. Provisions are included for systems in which each cyclically symmetrical sector also possesses a plane of reflective symmetry.

The following types of analysis may be performed:

- . static analysis with and without preload,
- . vibrational analysis with and without preload, and
- . buckling analysis with and without preload.

The EAL procedure for cyclically symmetrical structures without reflective symmetry is named CS. The procedure for cyclically symmetrical structures including reflective symmetry is named CSR. Throughout this report, the acronyms CS and CSR refer to cyclic symmetry without and with reflective symmetry, respectively.

1.1 CYCLICALLY SYMMETRICAL STRUCTURES

As illustrated in Fig. 1, a cyclically symmetrical structure consists of n identical sectors symmetrically arranged with respect to a central axis. The sectors are numbered consecutively from 1 to n .

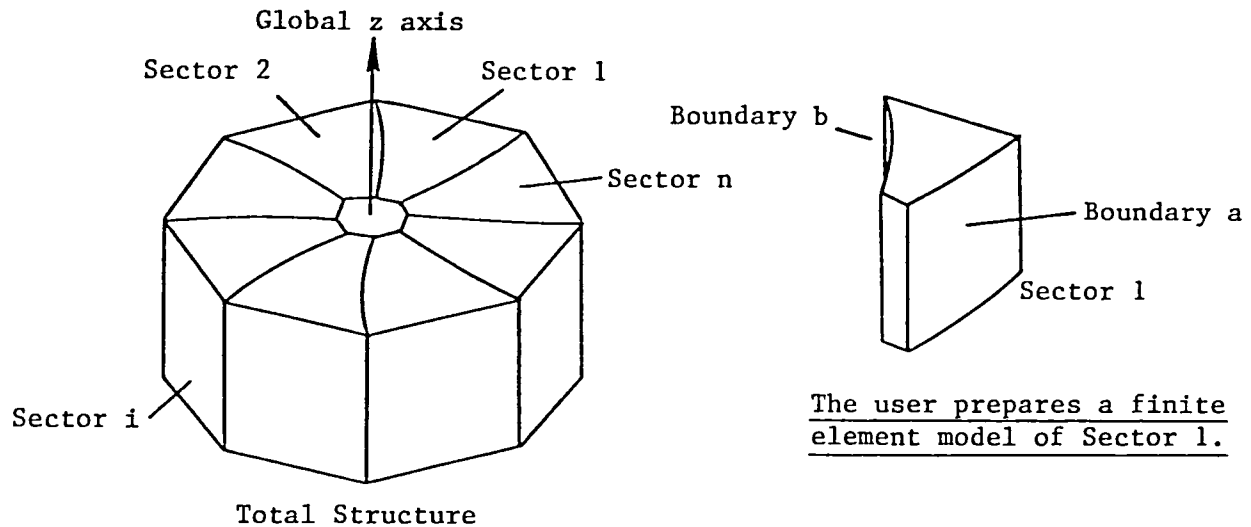


Figure 1. Cyclically Symmetrical Structure, No Reflective Symmetry Plane

If the individual sectors also possess a plane of reflective symmetry, as shown in Fig. 2, a finite element model of a symmetric half of one sector is required for the analysis.

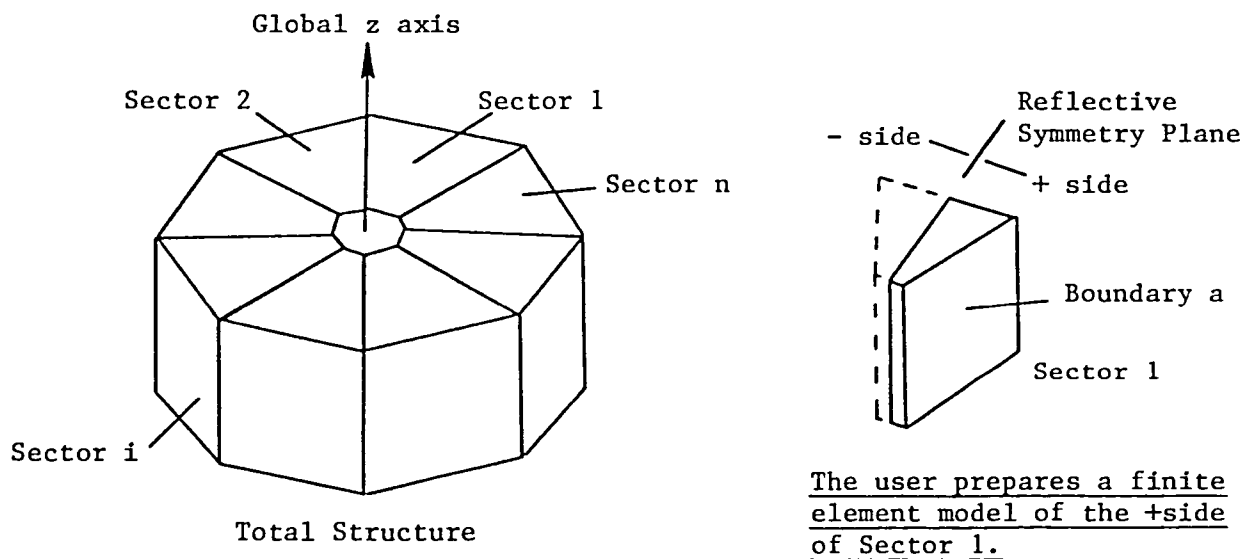


Figure 2. Cyclically Symmetrical Structure with Reflective Symmetry

Note that for models with reflective symmetry, the intersector boundaries must be planar.

As shown in Fig. 2, the modeled side (adjacent to boundary a) of sector 1 is called the +side, and the reflected side is called the -side.

In the following discussion, F_i and U_i are defined as follows:

F_i = the vector of applied nodal forces in sector i,
 U_i = the vector of nodal motions in sector i.

As shown in detail in Section 6, the following relations are characteristic of cyclically symmetrical structures:

$$F_i = \sum_{k=0}^m P_{kc} \cos(i-1) \frac{2\pi k}{n} + P_{ks} \sin(i-1) \frac{2\pi k}{n} \quad (1)$$

$$U_i = \sum_{k=0}^m Q_{kc} \cos(i-1) \frac{2\pi k}{n} + Q_{ks} \sin(i-1) \frac{2\pi k}{n} \quad (2)$$

n = number of sectors in the total structure, and
 $m = n/2$ if n is even,
 $= (n-1)/2$ if n is odd.

P_{kc} and P_{ks} are called symmetrical components of applied load. Q_{kc} and Q_{ks} are called symmetrical components of motion. k is called the circumferential harmonic number.

For cyclically symmetrical structures with a plane of reflective symmetry, the following definitions are used:

F_i^+ = the vector of applied nodal forces in sector i, +side,
 F_i^- = the vector of applied nodal forces in sector i, -side,
 U_i^+ = the vector of nodal motions in sector i, +side,
 U_i^- = the vector of nodal motions in sector i, -side.

The following relations are characteristic of structures with a plane of reflective symmetry:

$$F_i^+ = \frac{1}{2}(F_i^s + F_i^a), \quad F_i^- = \frac{1}{2}(F_i^s - F_i^a) \quad (3)$$

$$U_i^+ = \frac{1}{2}(U_i^s + U_i^a), \quad U_i^- = \frac{1}{2}(U_i^s - U_i^a), \quad (4)$$

where

F_i^S = the symmetric reflective component of applied nodal forces in sector i,
 F_i^a = the anti-symmetric reflective component of applied nodal forces in sector i,
 U_i^S = the symmetric reflective component of nodal motions in sector i,
 U_i^a = the anti-symmetric reflective component of nodal motions in sector i.

Solving Eqs. 3 and 4 for the symmetric and anti-symmetric reflective components of force and motion yields:

$$F_i^S = (F_i^+ + F_i^-), \quad F_i^a = (F_i^+ - F_i^-) \quad (5)$$

$$U_i^S = (U_i^+ + U_i^-), \quad U_i^a = (U_i^+ - U_i^-) \quad (6)$$

As shown in detail in Section 6, the following relations are characteristic of cyclically symmetrical structures with a plane of reflective symmetry.

$$F_i^a = \sum_{k=0}^m P_{kc}^a \cos(i-1) \frac{2\pi k}{n} + P_{ks}^a \sin(i-1) \frac{2\pi k}{n} \quad (7)$$

$$F_i^S = \sum_{k=0}^m P_{kc}^S \cos(i-1) \frac{2\pi k}{n} + P_{ks}^S \sin(i-1) \frac{2\pi k}{n} \quad (8)$$

$$U_i^a = \sum_{k=0}^m Q_{kc}^a \cos(i-1) \frac{2\pi k}{n} + Q_{ks}^a \sin(i-1) \frac{2\pi k}{n} \quad (9)$$

$$U_i^S = \sum_{k=0}^m Q_{kc}^S \cos(i-1) \frac{2\pi k}{n} + Q_{ks}^S \sin(i-1) \frac{2\pi k}{n} \quad (10)$$

n = number of whole sectors in the total structure (a whole sector includes both the +side and -side),

$m = n/2$, if n is even,
 $= (n-1)/2$, if n is odd.

P_{kc}^a , P_{ks}^a , P_{kc}^S , and P_{ks}^S are called symmetrical-reflective components of applied load. Q_{kc}^a , Q_{ks}^a , Q_{kc}^S , and Q_{ks}^S are called symmetrical-reflective components of motion.

As shown in Fig. 1, the two bounding surfaces of a sector are called boundary a and boundary b. Where U_{ai} is the boundary-a motion of sector i and U_{bi} is the motion of boundary b, the equation of constraint between adjacent sectors is

$$U_{a,i+1} = U_{bi}, \text{ for } i = 1, n, \quad (11)$$

where $U_{a,n+1} = U_{a1}$. To enforce Eq. 11, the finite element grid points on boundary a must coincide with the corresponding grid points on boundary b. As shown on Fig. 3, the joint reference frame associated with each boundary joint must be oriented so that the joint reference frame 2-axis is perpendicular to the plane that contains both the global z-axis and the boundary joint. Cylindrical joint reference frames are usually used to satisfy this requirement.

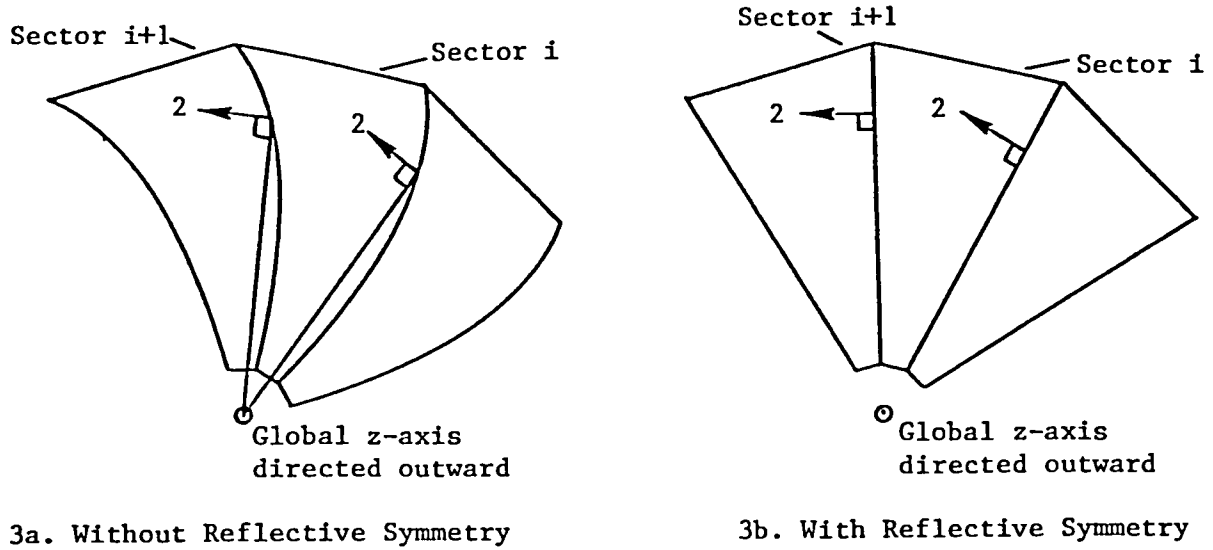


Figure 3. Boundary Joint Reference Frames

For reflective symmetry, Fig. 2, the equation of constraint between adjacent sectors is

$$U_{a,i+1}^+ = \bar{T} \cdot U_{ai}^-, \text{ for } i = 1, n. \quad (12)$$

where $U_{a,n+1}^+ = U_{a1}^+$

In Eq. 12, \bar{T} is a diagonal transformation matrix. To enforce Eq. 12, the joint reference frame associated with each joint on boundary a must be oriented as shown on Fig. 3. The joint reference frame 2-axis is perpendicular to the plane that contains both the global z-axis and the boundary joint. Cylindrical joint reference frames satisfy this requirement.

For vibrational and buckling analysis, eigensolutions are computed for user-designated values of the circumferential harmonic, k . For static analysis of an arbitrarily applied loading, the complete summations of Eq. 1 or Eqs. 9 and 10 are required for an exact solution. However, provisions are included for truncating the summation to user-selected values of k .

1.2 CAPABILITIES AND REQUIREMENTS OF THE EAL PROCEDURES

The EAL procedures for cyclically symmetrical structures include provisions for the following types of analyses:

- static analysis with and without preload,
- vibrational analysis with and without preload, and
- buckling analysis with and without preload.

All of the above types of analyses can be performed for structures with or without planes of reflective symmetry.

The procedures are based on the following requirements:

- The global Z axis of the sector 1 model is coincident with the central axis of the total structure,
- All joints lying on the central axis are fully constrained,
- The plane of reflective symmetry is either the XZ or YZ global plane of the sector 1 +side model,
- For each boundary joint, joint reference frames are defined for which the 2-axis is perpendicular to the plane that contains both the global z-axis and the boundary joint. See Figure 3. Cylindrical joint reference frames are usually used to satisfy this requirement.
- Joint motion constraints defined for the sector 1 model are symmetrically applied to sectors 2 through n,
- Preloads and active buckling loads must possess the same cyclic and reflective symmetry characteristics as the total structure.

Constraints, preloads, active buckling loads, and active static loads may be applied to boundary joints.

2. EXECUTION OF THE CYCLIC SYMMETRY PROCEDURES

The acronym CS is used to identify the sub-sections of section 2 that pertain to cyclically symmetrical structures with no plane of reflective symmetry. CSR is used to identify the sub-sections that pertain to cyclically symmetrical structures that do include planes of reflective symmetry.

Before executing the procedures described subsequently, the user must attach as EAL library 28 the file containing the cyclic symmetry command runstreams.

2.1 CS: CYCLIC SYMMETRY MODELS WITHOUT REFLECTIVE SYMMETRY

The following subsections, 2.1.1 through 2.1.4, present step-by-step instructions for using the cyclic symmetry procedures to compute static, vibrational, and buckling analyses for models with no plane of reflective symmetry.

2.1.1 CS: STATIC ANALYSIS PROCEDURE

To compute the static deformation of a cyclic symmetry model with no plane of reflective symmetry, proceed as follows:

| | |
|--|---|
| <pre>*XQT TAB START jts - - -</pre> | <p>All TAB data for the sector 1 model.</p> |
| <pre> JREF: NREF=nref ja1--: jb1---</pre> | <p>All joints on boundaries a and b have joint reference frames oriented as those shown on Fig. 3. Cylindrical joint reference frames, nref=-1, satisfy this requirement.</p> |
| <pre>*XQT ELD Eij: - - -</pre> | <p>Element definitions for sector 1.</p> |
| <pre>*XQT AUS TABLE(NJ=nb,TYPE=0): JA: J=1,nb: ja1: ja2:--- TABLE(NF=nb,TYPE=0):</pre> | <p>JA contains a list of the sector 1 joints that lie on boundary a. JB contains a list of the sector 1 joints on boundary b. These lists must be ordered so that joint jak in sector i+1 coincides with joint jbk in sector i.</p> |
| <pre>OUTLIB=5</pre> | <p>Loads and solution control data sets reside in Lib 5.</p> |
| <pre>TABLE(NI=18,NJ=1,TYPE=4): TITLE FORCE: J=1: 'Title</pre> | <p>Title used for labeling displacements and stress printout.</p> |
| <pre>TABLE(NJ=nls,TYPE=0): SECT FORC J=1,nls: sf1: sf2:--- SYSVEC: APPL FORC BLOCK 1: Sector sf1 loads BLOCK 2: Sector sf2 loads - - - BLOCK nls:---</pre> | <p>The loads defined in the ith block of APPL FORC are applied to sector sf1, the ith entry in SECT FORC.</p> |
| <pre>TABLE(NJ=nk,TYPE=0): HARMONICS J=1,nb: k1: k2:---</pre> | <p>The computed static solution summation (see Eq. 2, section 1.1), is to be truncated to include only those terms corresponding to harmonics k1, k2,---. If HARMONICS is not present in Lib 5, <u>all</u> harmonics are included in the summation.</p> |
| <pre>TABLE(NJ=nbse,TYPE=0): BACK SECTORS J=1,nbse: sb1: sb2:---</pre> | <p>Solution joint displacement vectors are to be computed for sectors sb1, sb2,---. If BACK SECTORS is not present in Lib 5, solution vectors will be produced for <u>all</u> sectors.</p> |

| | |
|--------------------------|--|
| *XQT U1 | |
| *(CONSTRAINTS) | TAB/CON input defining the constraints of |
| ZERO - - - | sector 1, see section 1.2. |
| *(LOADS PRE) | |
| SYSVEC: APPL FORC: - - - | Preload definition, if any, see section |
| ALPHA: CASE TITLE: - - - | 2.3. |
| *(CONSTRAINTS PRE) | Preload constraints, if different from |
| SYMMETRY PLANE= - - - | CONSTRAINTS, see section 2.3. |
| *(OPTIONS) | |
| !PROB='STAT | The problem type is static analysis. |
| !NSECTORS=n | The total structure consists of n sectors. |
| !VPRT=0: - - - | See Section 2.1.4 for a complete |
| | list of the available options. |
| *(- - - -) | Optional runstream elements described |
| | in Section 2.8, Special Controls. |
| *PERFORM(CS) | Compute the static solution. |

2.1.2 CS: VIBRATIONAL ANALYSIS PROCEDURE

To compute the vibrational modes and frequencies for a cyclic symmetry model with no plane of reflective symmetry, proceed as follows:

*XQT TAB
START jts
- - -

All TAB data for the sector 1 model.

JREF: NREF=nref
ja1---: jb1---

All joints on boundaries a and b have joint reference frames oriented as those shown on Fig. 3. Cylindrical joint reference frames, nref=-1, satisfy this requirement.

*XQT ELD
Elj: - - -

Element definitions for sector 1.

*XQT AUS
TABLE(NJ=nb,TYPE=0):
JA: J=1,nb: ja1: j2:---
TABLE(NF=nb,TYPE=0):
JB: J=1,nb: jb1: jb2:---

JA contains a list of the sector 1 joints that lie on boundary a. JB contains a list of the sector 1 joints on boundary b. These lists must be ordered so that joint jak in sector i+1 coincides with joint jbk in sector 1.

OUTLIB=5

Control data sets reside in Lib 5.

TABLE(NJ=nk,TYPE=0):
HARMONICS
J=1,nb: k1: k2:---

Compute modal solutions for harmonics k1, k2,---. If HARMONICS is omitted, all harmonic solutions are computed.

TABLE(NJ=nbsc,TYPE=0):
BACK SECTORS
J=1,nbsc: sb1: sb2:---

Compute eigenvectors for sectors sb1, sb2,---. If BACK SECTORS is omitted, vectors are produced for all sectors.

*XQT U1
*(CONSTRAINTS)
ZERO - - -

TAB/CON input defining the constraints of sector 1, see section 1.2.

*(LOADS PRE)
SYSVEC: APPL FORC: - - -
ALPHA: CASE TITLE: - - -

Preloads, if any, see section 2.3.

*(CONSTRAINTS PRE)
SYMMETRY PLANE= - - -

Preload constraints, if different from CONSTRAINTS, see section 2.3.

*(OPTIONS)

!NSECTORS=n
!MNAME='CEM
!G=386:---

The total structure consists of n sectors.
See Section 2.1.4 for a complete list of
the available options.

*(- - - -)

Optional runstream elements described in
Section 2., Special Controls.

*PERFORM(CS)

Compute the vibrational solution.

2.1.3 CS: BUCKLING ANALYSIS PROCEDURE

To compute the buckling modes and eigenvalues for a cyclic symmetry model with no plane of reflective symmetry, proceed as follows:

| | |
|--|--|
| *XQT TAB START jts - - - | All TAB data for the sector 1 model. |
| JREF: NREF=nref ja1---: jb1--- | All joints on boundaries a and b have joint reference frames oriented as those shown on Fig. 3. Cylindrical joint reference frames, nref=-1, satisfy this requirement. |
| *XQT ELD EXX: - - - | Element definitions for sector 1. |
| *XQT AUS TABLE(NJ=nb,TYPE=0): JA: J=1,nb: ja1: ja2:--- TABLE(NF=nb,TYPE=0): | JA contains a list of the sector 1 joints that lie on boundary a. JB contains a list of the sector 1 joints on boundary b. These lists must be ordered so that joint jak in sector i+1 coincides with joint jbk in sector i. |
| OUTLIB=5 | Control data sets reside in Lib 5. |
| TABLE(NJ=nk,TYPE=0): HARMONICS J1,nb: k1: k2:--- | Compute buckling solutions for harmonics k1, k2,---. If HARMONICS is omitted, <u>all</u> harmonic solutions are computed. |
| TABLE(NJ=nbse,TYPE=0): BACK SECTORS J=1,nbse: sb1: sb2:--- | Compute eigenvectors for sectors sb1, sb2,---. If BACK SECTORS is omitted, vectors are produced for <u>all</u> sectors. |
| *XQT U1 *(CONSTRAINTS) ZERO - - - | TAB/CON input defining the constraints of sector 1, see section 2.4. |
| *(LOADS) SYSVEC: APPL FORC:--- ALPHA: CASE TITLE:--- | Loads for which buckling solutions are to be computed, see section 2.4 for details. |
| *(LOADS PRE) SYSVEC: APPL FORC:--- ALPHA: CASE TITLE:--- | Preloads, if any, see section 2.3. |
| *(CONSTRAINTS PRE) SYMMETRY PLANE=--- | Preload constraints, if different from CONSTRAINTS, see section 2.3. |

| | |
|---|--|
| <pre> *(OPTIONS) !PROB='BUCK !NSECTORS=n !INIT=4: !NREQ=1:--- *(- - - -) *PERFORM(CS) </pre> | <p>The problem type is buckling analysis.</p> <p>The total structure consists of n sectors. See Section 2.1.4 for a complete list of the available options.</p> <p>Optional runstream elements described in Section 2.8, Special Controls.</p> <p>Compute the buckling solution.</p> |
|---|--|

2.1.4 OPTIONAL REGISTERS

As discussed in Sections 2.1.1, 2.1.2, and 2.1.3, values for the registers tabulated below can be changed through use of the data runstream element OPTIONS.

The following registers pertain to static, vibrational and buckling analysis.

| <u>Register</u> | <u>Default Value</u> | <u>Meaning</u> |
|-----------------|----------------------|---|
| !PROB | 'VIBR | Problem Type: 'VIBR, 'BUCK, or 'STAT. |
| !MNAME | 'DEM | Mass matrix name, usually DEM or CEM. As described in Section 2.5, MNAME is automatically added to the rigid mass data set, RMASS, to form the total mass matrix. |
| !G | 1 | Mass = weight/"G". |
| !SPDP | 2 | =1, Single Precision Stiffness Matrix. =2, Double Precision Stiffness Matrix. |
| !NBSC | 1 | If NBSC=0, no solution vectors are produced for the sectors. This overrides the runstream element BACK SECTORS. If NBSC=1, BACK SECTORS directs the computation of solution vectors as discussed in Sections 2.1.1 - 2.1.3. |
| !ZERO | 1.E-4 | Floating Point Zero Test Value. If the absolute value of $\sin \theta$ is less than ZERO, $\theta = 0$. |
| !KSAV | 1 | =1, Harmonic Libs are saved, see Section 2.10. =0, Harmonic Libs are not saved. |
| !QSAV | 0 | =1, Harmonic Solution Libs, LIB 6, are saved, as discussed in Section 2.10. =0, Harmonic Solution Libs are not saved. |
| !VPRT | 1 | =1, Sector Solution Vectors are printed. =0, Sector Solution Vectors are not printed. |
| !LIB1 | 1 | Library Assignment, see Section 2.10. |
| !LIB2 | 2 | Library Assignment, see Section 2.10. |
| !LIB3 | 3 | Library Assignment, see Section 2.10. |
| !LIB4 | 4 | Library Assignment, see Section 2.10. |
| !LIB5 | 5 | Library Assignment, see Section 2.10. |
| !LIB6 | 6 | Library Assignment, see Section 2.10. |
| !JROT | 1 | Sector is rotated about joint JROT for ACCL loads, see Sections 2.3 and 2.4. |
| !ERCK | 1 | =1, Data errors result in execution termination =0, Data errors are printed, but execution continues. |

The following registers pertain only to static analysis.

| <u>Register</u> | <u>Default Value</u> | <u>Meaning</u> |
|-----------------|----------------------|--|
| !SET | 1 | 3rd word of the input data sets defining the applied loads: TITLE FORCE "SET", SECT FORC "SET", and APPL FORC "SET". |
| !ES | 1 | =1, Sector stresses are printed via ES. =0, Sector stresses are not printed. |

The following registers pertain only to vibrational and buckling analyses.

| <u>Register</u> | <u>Default Value</u> | <u>Meaning</u> |
|-----------------|----------------------|--|
| !INIT | 8 | EIG RESET |
| !SHIFT | 0 | EIG RESET |
| !NDYN | 8 | EIG RESET |
| !NREQ | 4 | EIG RESET |
| !V1 | 0 | EIG RESET |
| !V2 | 0 | EIG RESET |
| !NVECTORS | "INIT" | Number of eigenvectors to compute for each of the sectors named in BACK SECTORS, see sections 2.1.2 and 2.1.3. |
| !NEVALS | "INIT" | Number of eigenvalues to be stored in the solution library, Lib 5, see Section 3.1.1. |

2.2 CSR: CYCLIC SYMMETRY MODELS WITH REFLECTIVE SYMMETRY

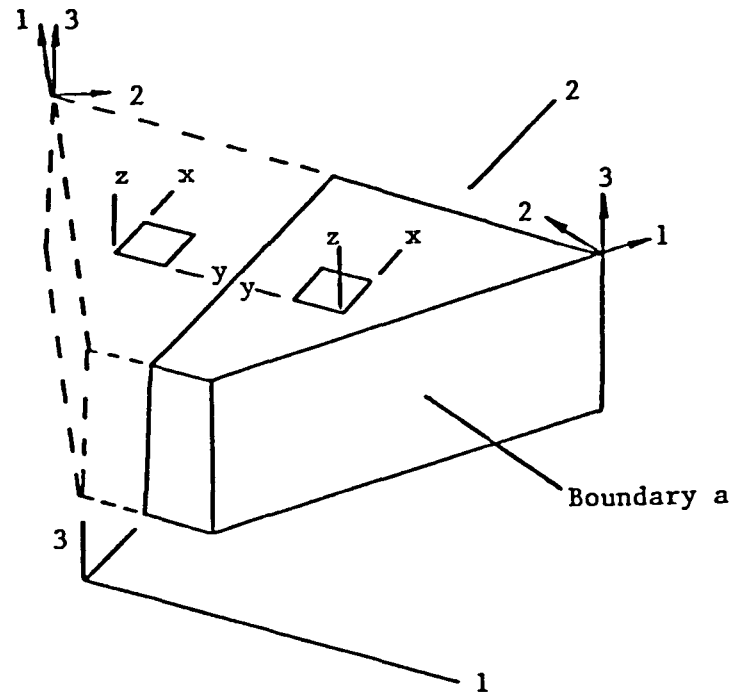


Figure 4. CSR: Joint Reference Frames and Element Reference Frames

Figure 4 illustrates a sector from a cyclically symmetrical structure. The 2-3 plane is a reflective symmetry plane. That half of the sector, outlined in solid lines, is called the +side of the sector and represents the finite element model that must be prepared by the user. The reflected half of the sector, outlined in dashed lines, is called the -side of the sector. Typical joint reference frames and element reference frames are shown on Figure 4. Note that the -side reference frames are left handed. Applied force vectors and joint motion vectors for the -side of all sectors are defined relative to left hand reference frames. Similarly, element stresses for the -side of all sectors are relative to left hand element reference frames. The following subsections, 2.2.1 through 2.2.4, present step-by-step instructions for using the cyclic symmetry procedure to compute static, vibrational, and buckling analyses for models with a plane of reflective symmetry.

2.2.1 CSR: STATIC ANALYSIS PROCEDURE

To compute the static deformation of a cyclic symmetry model with reflective symmetry, proceed as follows:

```
*XQT TAB
START jts
- - -
```

All TAB data for the sector 1 +side model.

```
JREF: NREF=nref
ja1--
```

All joints on boundary a have joint reference frames oriented as those shown on Fig. 3. Cylindrical joint reference frames, nref=-1, satisfy this requirement.

```
*XQT ELD
Eij: - - -
```

Element definitions for sector 1, +side.

```
*XQT AUS
TABLE(NJ=nb,TYPE=0):
JA: J=1,nb: ja1: ja2:---
```

JA contains a list of the sector 1 joints that lie on boundary a.

```
OUTLIB=5
```

Loads and solution control data sets reside in Lib 5.

```
TABLE(NI=18,NJ=1,TYPE=4):
TITLE FORCE: J=1: 'Title
```

Title used for labeling displacements and stress printout.

```
TABLE(NJ=nls,TYPE=0):
SECT FORC
J=1,nls: sf1: sf2:---
SYSVEC: F+ FORC
BLOCK 1: Loads on sf1,
+side
BLOCK 2: Loads on sf2,
+side
```

The loads defined in the ith block of F+ FORC are applied to the +side of sector sfi, the ith entry in SECT FORC. The loads defined in the ith block of F- FORC are applied to the -side of sector sfi. Note that all -side forces are defined relative to left-handed joint reference frames, see Fig. 4. All three of the above data sets must be present in Lib 5.

```
---
BLOCK nls:---
SYSVEC: F- FORC
BLOCK 1: Loads on sf1,
-side
BLOCK 2: Loads on sf2,
-side
---
BLOCK nls:---
```

```
TABLE(NJ=nk,TYPE=0):
HARMONICS
J=1,nb: k1: k2:---
```

The computed static solution summations (see Eq. 9 & 10, Section 1.1), are to be truncated to include only those terms corresponding to harmonics k1, k2,---. If HARMONICS is not present in Lib 5, all harmonics are included in the summation.

| | |
|--|---|
| TABLE(NJ=nbsc,TYPE=0): BACK SECTORS J=1,nbsc: sb1: sb2:--- | Solution joint displacement vectors are to be computed for both sides of sectors sb1, sb2,---. If BACK SECTORS is not present in Lib 5, solution vectors will be produced for <u>all</u> sectors. |
| *XQT U1 *(CONSTRAINTS) ZERO--- | TAB/CON input defining the constraints for the +side of sector 1, see section 1.2. |
| *(LOADS PRE) SYSVEC: APPL FORC: - - - ALPHA: CASE TITLE: - - - | Preloads, if any, see section 2.3. |
| *(CONSTRAINTS PRE) SYMMETRY PLANE= - - - | Preload constraints, if different from CONSTRAINTS, see section 2.3. |
| *(OPTIONS) !PROB='STAT | The problem type is static analysis. |
| !NSECTORS=n | The total structure consists of n whole sectors. A whole sector includes both the +side and -side. |
| !VPRT=0: - - - | See Section 2.2.4 for a discussion of the available options. |
| *(- - - -) | Optional runstream elements described in Section 2.8, Special Controls. |
| *PERFORM(CSR) | Compute the static solution. |

2.2.2 CSR: VIBRATIONAL ANALYSIS PROCEDURE

To compute the vibrational modes and frequencies for a cyclic symmetry model with reflective symmetry, proceed as follows:

| | |
|--|--|
| *XQT TAB START jts - - - | All TAB data for the sector 1 +side model. |
| JREF: NREF=nref ja1--- | All joints on boundary a have joint reference frames oriented as those shown on Fig. 3. Cylindrical joint reference frames, nref=-1, satisfy this requirement. |
| *XQT ELD Eij: - - - | Element definitions for sector 1, +side. |
| *XQT AUS TABLE(NJ=nb,TYPE=0): JA: J=1,nb: ja1: ja2:--- | JA contains a list of the sector 1 joints that lie on boundary a. |
| OUTLIB=5 | Control data sets reside in Lib 5. |
| TABLE(NJ=nk,TYPE=0): HARMONICS J=1,nb: k1: k2:--- | Compute modal solutions for harmonics k1, k2,---. If HARMONICS is omitted, <u>all</u> harmonic solutions are computed. |
| TABLE(NJ=nbsc,TYPE=0): BACK SECTORS J=1,nbsc: sb1: sb2:--- | Compute eigenvectors for both sides of sectors sb1, sb2---. If BACK SECTORS is omitted, vectors are produced for <u>all</u> sectors. |
| *XQT U1 *(CONSTRAINTS) ZERO - - - | TAB/CON input defining constraints for the +side of sector 1, see section 1.2. |
| *(LOADS PRE) SYSVEC: APPL FORC: - - - ALPHA: CASE TITLE: - - - | Preloads, if any, see section 2.3. |
| *(CONSTRAINTS PRE) SYMMETRY PLANE= - - - | Preload constraints, if different from CONSTRAINTS, see section 2.3. |
| *(OPTIONS) !NSECTORS=n | The total structure consists of n whole sectors. A whole sector includes both the +side and -side. |
| !MNAME='CEM !G=386:--- | See Section 2.2.4 for a discussion of the available options. |
| *(- - -) | Optional runstream elements described in Section 2.8, Special Controls. |
| *PERFORM(CSR) | Compute the vibrational solution. |

2.2.3 CSR: BUCKLING ANALYSIS PROCEDURE

To compute the buckling modes and eigenvalues for a cyclic symmetry model with reflective symmetry, proceed as follows:

| | |
|--|--|
| *XQT TAB START jts - - - | All TAB data for the sector 1 +side model. |
| JREF: NREF=nref ja1--- | All joints on boundary a have joint reference frames oriented as those shown on Fig. 3. Cylindrical joint reference frames, nref=-1, satisfy this requirement. |
| *XQT ELD Elj: - - - | Element definitions for sector 1, +side. |
| *XQT AUS TABLE(NJ=nb,TYPE=0): JA: J=1,nb: ja1: ja2:--- | JA contains a list of the sector 1 joints that lie on boundary a. |
| OUTLIB=5 | Control data sets reside in Lib 5. |
| TABLE(NJ=nk,TYPE=0): HARMONICS J1,nb: k1: k2:--- | Compute buckling solutions for harmonics k1, k2,---. If HARMONICS is omitted, <u>all</u> harmonic solutions are computed. |
| TABLE(NJ=nbsc,TYPE=0): BACK SECTORS J=1,nbsc: sb1: sb2:--- | Compute eigenvectors for both sides of sectors sb1, sb2,---. If BACK SECTORS is omitted, vectors are produced for <u>all</u> sectors. |
| *XQT U1 *(CONSTRAINTS) ZERO | TAB/CON input defining constraints for the +side of sector 1, see section 2.4. |
| *(LOADS) SYSVEC: APPL FORC:--- ALPHA: CASE TITLE:--- | Loads for which buckling solutions are to be computed, see section 2.4 for details. |
| *(LOADS PRE) SYSVEC: APPL FORC:--- ALPHA: CASE TITLE:--- | Preloads, if any, see section 2.3. |
| *(CONSTRAINTS PRE) SYMMETRY PLANE=--- | Preload constraints, if different from CONSTRAINTS, see section 2.3. |

| | |
|---|--|
| <pre> *(OPTIONS) !PROB='BUCK !NSECTORS=n !INIT=4: !NREQ=1:--- *(- - - -) *PERFORM(CSR) </pre> | <p>The problem type is buckling analysis.</p> <p>The total structure consists of n whole sectors. A whole sector includes both the +side and -side.</p> <p>See Section 2.2.4 for a discussion of the available options.</p> <p>Optional runstream elements described in Section 2.8, Special Controls.</p> <p>Compute the buckling solution.</p> |
|---|--|

2.2.4 CSR: OPTIONAL REGISTERS

As discussed in Sections 2.2.1, 2.2.2 and 2.2.3, values for the registers tabulated below can be changed through use of the data runstream element OPTIONS.

The following registers pertain to static, vibrational, and buckling analysis.

| <u>Register</u> | <u>Default Value</u> | <u>Meaning</u> |
|-----------------|----------------------|--|
| !PROB | 'VIBR | Problem Type: 'VIBR, 'BUCK, or 'STAT. |
| !MNAME | 'DEM | Mass matrix name, usually DEM or CEM. As described in Section 2.5, MNAME is automatically added to the rigid mass data set, RMASS, to form the total mass matrix. |
| !G | 1 | Mass= weight/"G". |
| !SPDP | 2 | =1, Single Precision Stiffness Matrix. =2, Double Precision Stiffness Matrix. |
| !CONS | 10 | The number of the constraint condition made up of the runstream element CONSTRAINTS or CONSTRAINTS PRE plus symmetry plane constraints on the reflective plane. |
| !CONA | 20 | The number of the constraint condition made up of the runstream element CONSTRAINTS or CONSTRAINTS PRE plus anti-symmetry plane constraints on the reflective plane. |
| !RFLP | 1 | Global axis that is normal to the reflective symmetry plane. |
| !NBSC | 1 | If NBSC=0, no solution vectors are produced for the sectors. This overrides the runstream element BACK SECTORS. If NBSC=1, BACK SECTORS direct the computation of solution vectors as discussed in sections 2.2.1 - 2.2.3. |
| !Zero | 1.E-4 | Floating Point Zero Test Value. If the absolute value of $\sin \theta$ is less than ZERO, $\theta = 0$. |
| !KSAV | 1 | =1, Harmonic Libs are saved, see Section 2.10. =0, Harmonic Libs are not saved. |
| !QSAV | 0 | =1, Harmonic Solution Libs, Lib 6, are saved as discussed in section 2.10. =0, Harmonic Solution Libs are not saved. |
| !VPRT | 1 | =1, Sector Solution Vectors are printed. =0, Sector Solution Vectors are not printed. |
| !LIB1 | 1 | Library Assignment, see Section 2.10. |
| !LIB2 | 2 | Library Assignment, see Section 2.10. |
| !LIB3 | 3 | Library Assignment, see Section 2.10. |
| !LIB4 | 4 | Library Assignment, see Section 2.10. |
| !LIB5 | 5 | Library Assignment, see Section 2.10. |
| !LIB6 | 6 | Library Assignment, see Section 2.10. |
| !JROT | 1 | Sector is rotated about joint JROT for ACCL loads, see sections 2.3 and 2.4. |
| !ERCK | 1 | =1, Data errors result in execution termination =0, Data errors are printed, but execution continues. |

The following registers pertain only to static analysis.

| <u>Register</u> | <u>Default Value</u> | <u>Meaning</u> |
|-----------------|--------------------------|---|
| !SET | 1 | Static solution set number. |
| !ES | 1 | =1, Sector stresses are printed via ES. =0, Sector stresses are not printed. |

The following registers pertain only to vibrational and buckling analyses.

| <u>Register</u> | <u>Default Value</u> | <u>Meaning</u> |
|-----------------|--------------------------|--|
| !INIT | 8 | EIG RESET |
| !SHIFT | 0 | EIG RESET |
| !NDYN | 8 | EIG RESET |
| !NREQ | 4 | EIG RESET |
| !V1 | 0 | EIG RESET |
| !V2 | 0 | EIG RESET |
| !NVECTORS | "INIT" | Number of eigenvectors to compute for both sides of each of the sectors named in BACK SECTORS, see sections 2.2.2 and 2.2.3. |
| !NEVALS | "INIT" | Number of eigenvalues to be stored in the solution library, Lib 5, see section 2.10. |

2.3 PRELOAD AND PRELOAD CONSTRAINTS

As discussed in Sections 2.1 and 2.2, cyclically symmetrical preloads are defined through the data runstream element, LOADS PRE. In addition to LOADS PRE, the preload definition may also include the runstream elements ACCL PRE and/or CF PRE. The preload runstream elements are constructed as follows:

```
*XQT U1
*(LOADS PRE) $ See Section 6, Vol 1, EAL Reference Manual
  ALPHA:      CASE TITLE: 1'Preload Title
  SYSVEC:     APPLIED FORCES: - - -
  TABLE:     NODAL TEMPERATURES:- - -
  TABLE:     NODAL PRESSURES: - - -
  ELDATA:     TEMPERATURES Eij: - - -
  ELDATA:     PRESSURES Eij: - - -
  ELDATA:     DISLOCATIONS Eij: - - -
*(ACCL PRE) $ Acceleration Component of the Preload
  ax ay az rx ry rz $ See below
*(CF PRE) $ Centrifugal Component of the Preload
  m k wx wy wz xo yo zo$ See below
```

ACCL Input:

Items defined via ACCL PRE are:

ax, ay, az = linear acceleration in the global x, y, and z directions.

rx, ry, rz = rotational accelerations about axes parallel to the global x, y, and z axes, passing through the joint identified by register JROT.
Default: !JROT= 1.

As an example, suppose that the global 3 axis points vertically downward, and that acceleration due to gravity is 386. The following would define 1 G gravitational preload:

```
*(ACCL PRE)
  0. 0. 386. 0. 0. 0.
```

CF Input:

m = name of mass matrix to be used (e.g. DEM) in computing centrifugal forces. As discussed in Section 2.5, MTOT is the name assigned to the total mass matrix, if rigid masses are included.

k = name of the sector k matrix.

wx, wy, wz = angular velocity components relative to the global reference frame.

xo, yo, zo = position coordinates of the spin center relative to the global frame.

The runstream element LOADS PRE is mandatory for preloads to be included. ACCL PRE and CF PRE are optional.

As outlined in sections 2.1 and 2.2, the data runstream element CONSTRAINTS PRE contains the TAB/CON data defining the preload constraint condition. If CONSTRAINTS PRE is not present, the constraints defined via the runstream element CONSTRAINTS are used for the preload computations.

Preloads and preload constraints may be applied to any sector joints, boundary or interior. Preloads and preload constraints defined for sector 1 are assumed to possess the same cyclic and reflective symmetry characteristics as the total structure.

2.4 BUCKLING ACTIVE LOADS AND CONSTRAINTS

As discussed in sections 2.1.3 and 2.2.3, cyclically symmetrical buckling loads are defined through the data runstream element, LOADS. In the following, n3bl is the 3rd word of all buckling load data sets. If preloads are present, n3bl must be set equal to 2. If preloads are absent, n3bl=1. If omitted, n3bl defaults to 1. In addition to LOADS, the active buckling load definition may also include the runstream elements ACCL and/or CF. The buckling load runstream elements are constructed as follows:

```
*XQT U1
*(LOADS) $ See Section 6, Vol. 1, EAL Reference Manual
  ALPHA:  CASE  TITLE n3bl:  1' Buckling Load Title
  SYSVEC:  APPL  FORCE n3bl:  - - -
  TABLE:  NODAL PRESS n3bl:  - - -
  TABLE:  NODAL TEMPS n3bl:  - - -
  ELDATA:  TEMPS EXX   n3bl:  - - -
  ELDATA:  PRESS EXX   n3bl:  - - -
  ELDATA:  DISLO EXX   n3bl:  - - -
*(ACCL) $ Acceleration Component of the Buckling Load
  ax ay az rx ry rz
*(CF) $ Centrifugal Component of the Buckling Load
  m k wx wy wz xo yo zo
```

ACCL and CF input are the same as ACCL PRE and CF PRE which are discussed in Section 2.3.

The runstream element LOADS is mandatory for buckling analysis. ACCL and CF are optional.

The constraint condition defined via the runstream element CONSTRAINTS PRE, if it is present in Lib 29, is used to compute the geometric stiffness matrix, KG, for the buckling eigensolution. If CONSTRAINTS PRE is not present in Lib 29, KG is computed using CONSTRAINTS. The buckling eigensolution is computed using the constraint condition defined in CONSTRAINTS.

Note that for preloaded buckling problems, both the preload KG and the buckling KG are computed using the same constraint condition.

Active buckling loads and buckling constraints defined for sector 1 are assumed to possess the same cyclic and reflective symmetry characteristics as the total structure.

2.5 MASS MATRICES and RIGID MASS DATA

To include rigid masses in the sector model, insert in LIB1 the SYSVEC format data set RMASS. RMASS can be created with either TAB/RMASS or AUS/SYSVEC. RMASS is automatically added to the sector mass matrix (defined by the register MNAME as discussed in Sections 2.1.4 and 2.2.4.) to form the total mass, MTOT. MTOT is then used by the cyclic symmetry procedures as the sector mass matrix.

2.6 SPECTRAL SHIFTS

Spectral shifting is included in a vibrational or buckling analysis by inputting a non-zero value for the register SHIFT through the data runstream element OPTIONS, see sections 2.1.4 and 2.2.4. The shifted stiffness matrix KSHF is then used by the cyclic symmetry procedures as the sector stiffness matrix. Spectral shifts may be used with either preloaded or non-preloaded models.

2.7 RESTART PROCEDURE

Restarted cyclic symmetry executions may be initiated through either of the following commands:

- *CALL (CS RESTART) \$ No Reflective Symmetry Plane, or
- *CALL (CSR RESTART) \$ Including Reflective Symmetry

Provisions are included for the following kinds of restarted executions:

- Computing additional harmonic solutions. For vibrational or buckling analyses, additional solutions are computed for specified harmonic values. For static analysis, this kind of restart is used to compute additional terms for a previously truncated solution summation (see Eq. 2, Section 1.1). Consequently, newly computed harmonic components are added to the existing solution data sets.
- Performing additional types of analyses, or computing static solutions for additional loads. For this kind of restart, the stiffness matrices and factored stiffness matrices used for previously computed harmonic solutions may be retrieved and used directly. See section 2.10 for instructions on storage and retrieval of the harmonic matrices.

Before restarting a cyclic symmetry execution, attach the files that correspond to EAL Libraries LIB1, LIB4, and LIB5 (see section 2.10 for library descriptions). For restarting, proceed as follows:

*XQT AUS

| | |
|---|--|
| OUTLIB=5 | Control data sets reside in Lib 5. |
| TABLE(NJ=nb,TYPE=0) HARMONICS J=1,nk: k1: k2:--- | Solutions are to be computed for harmonics k1, k2,---. |
| TABLE(NJ=nbse,TYPE=0) BACK SECTORS J=1,NK: k1: k2:--- | Solution vectors are to be computed for sectors sb1, sb2,---. |

*XQT U1

*(OPTIONS)

| | |
|--------------|----------------------|
| !PROB= 'VIBR | Vibrational analysis |
| = 'BUCK | Buckling analysis |
| = 'STAT | Static analysis |

| | |
|---------------|--|
| !VPRT= 0: --- | See Sections 2.1.4 and 2.2.4 for a discussion of the available options. |
|---------------|--|

| | |
|------------|--|
| *(- - - -) | Optional runstream elements described in Section 2.8, Special Controls. |
|------------|--|

| | |
|---|---------------------------------|
| *PERFORM (CS RESTART), or *PERFORM (CSR RESTART) | Initiate the restarted analysis |
|---|---------------------------------|

2.8 SPECIAL CONTROLS

In the cyclic symmetry procedures, many *XQT commands are followed by optional DCALL commands, such as:

*XQT SEQ
*DCALL, ROPT (SEQ OPTIONS)

This gives the user a means of inputting special processor resets or options. Optional runstream elements that are recognized by the cyclic symmetry procedures, are:

*(SEQ OPTIONS)
*(TAN OPTIONS)
*(LSU OPTIONS)
*(RSI OPTIONS), for either RSI or DRSI
*(EIG OPTIONS)
*(SSOL OPTIONS)
*(ES OPTIONS)
*(GSF OPTIONS), for the EMBED operation
*(KG OPTIONS)

Note that calls to other procedures may be initiated through an optional runstream element. For example, static accuracy improvement or eigen-solution check procedures may be called by SSOL OPTIONS or EIG OPTIONS.

ES OPTIONS can be used to control the quantity and nature of stress print. If a subset of elements is chosen through ES OPTIONS, also include the register action command, !JUMP=1, for example:

```
*XQT U1
*(ES OPTIONS)      END
  E21 1: E43 4  10,20: !JUMP=1
*
```

JUMP = 0 (the default value) causes the ES command ALL to be executed.

Optional data runstream elements may be supplied for each harmonic solution that is computed during an execution. For example, at the beginning of execution for harmonic k1, the following *DCALL is performed:

```
*DCALL, ROPT (OPTIONS K k1)
```

Consequently, the user may provide optional registers that differ for each harmonic solution.

2.9 ERROR MESSAGES

Before any actual computations are performed by the cyclic symmetry procedures, the input data sets are diagnosed for apparent errors.

The following list of error messages pertain to the cyclic symmetry models with no reflective symmetry plane.

1. The number of sectors must exceed 0. Check the runstream element (OPTIONS).
2. JA data set is not present in Lib 1.
3. JB data set is not present in Lib 1.
4. The dimensions of JA and JB data sets are not equal.
5. The number of defined boundary joints exceeds the total number of joints in the sector model.
6. Joint numbers in the JA data set exceed the total number of joints in the sector model.
7. Joint numbers in the JA data set are less than 1.
8. Joint numbers in the JB data set exceed the total number of joints in the sector model.

9. Joint numbers in the JB data set are less than 1.
10. Duplicate joint numbers are present in the JA and JB data sets.
11. Cylindrical joint reference frames have not been specified for all boundary joints appearing in the JA and JB data sets. If joint reference frames other than cylindrical are defined for the boundary joints, set register ERCK=0 in the runstream element OPTIONS, see Section 2.1.4. These joint reference frames must satisfy the requirements of Section 1.2, or the resulting solution will be in error.
12. Specified harmonic values exceed the maximum. Check the data set (HARMONICS) in Lib 5.
13. Specified harmonic value is less than zero. Check the data set (HARMONICS) in Lib 5.
14. All sectors specified by the data set (BACK SECTORS) are not within the bounds of 1 and "NSECTORS".

The following error messages pertain to static load input:

15. Data set not present in Lib 5: SECT FORC "SET".
16. Data set not present in Lib 5: APPL FORC "SET".
17. The number of blocks in (APPL FORC "SET") does not equal NJ of (SECT FORC "SET").
18. All sectors specified by the data set (SECT FORC "SET") are not within the bounds of 1 and "NSECTORS".

The following list of error messages pertain to cyclic symmetry models with a reflective symmetry plane:

1. The number of sectors must exceed 0. Check the runstream element (OPTIONS).
2. JA data set is not present in Lib. 1.
3. Too many boundary joints defined.
4. Joint numbers in the JA data set exceed the total number of joints in the sector model.
5. Joint numbers in the JA data set are less than 1.
6. Duplicate joint numbers are present in the JA.

7. Cylindrical joint reference frames have not been specified for all boundary joints appearing in the JA data set. If joint reference frames other than cylindrical are defined for the boundary joints, set register ERCK=0 in the runstream element OPTIONS, see Section 2.2.4. These joint reference frames must satisfy the requirements of Section 1.2, or the resulting solution will be in error.
8. Specified harmonic values exceed the maximum. Check the data set (HARMONICS) in Lib 5.
9. Specified harmonic value is less than zero. Check the data set (HARMONICS) in Lib 5.
10. All sectors specified by the data set (BACK SECTORS) are not within the bounds of 1 and "NSECTORS".

The following error messages pertain to static load input:

11. Data set not present in Lib 5: SECT FORC "SET".
12. Data set not present in Lib 5: F+ FORC "SET".
13. Data set not present in Lib 5: F- FORC "SET".
14. The number of blocks in data set (F+ FORC "SET") does not equal the number of blocks in (F- FORC "SET").
15. The number of blocks in (F+ FORC "SET") does not equal NJ of (SECT FORC "SET").
16. All sectors specified by the data set (SECT FORC "SET") are not within the bounds of 1 and "NSECTORS".

If any of the above errors are encountered, execution is terminated in the default mode. However, if the register !ERCK=0 (see sections 2.1.4 and 2.2.4), error messages are printed, but the execution continues.

2.10 LIBRARY CONFIGURATION

The following EAL libraries are used by the cyclic symmetry procedures. Register notation is used to identify each library. As discussed in sections 2.1.4 and 2.2.4, LIB1 through LIB6 default to 1 through 6, respectively.

| <u>Library</u> | <u>Configuration</u> |
|----------------|---|
| LIB1 | Sector library containing the user supplied finite element model of sector 1. |
| LIB2 | For each circumferential harmonic solution that is computed, LIB2 contains the harmonic stiffness matrix, factored stiffness matrix, mass matrix, etc. Subject to user control, LIB2 is stored as a LIBLIB data set in LIB4 upon completion of each harmonic solution. |
| LIB3 | Contains temporary data sets. |
| LIB4 | Contains LIBLIB data sets for each circumferential harmonic model. The data set stored for harmonic k is named: KLIB HARM k . |
| LIB5 | For static analysis problems, LIB5 contains the input applied load data sets and the corresponding sector static displacement vectors. For vibrational and buckling analysis problems, LIB5 contains the solution eigenvalue and sector eigenvector data sets. |
| LIB6 | For each circumferential harmonic solution that is computed, LIB6 is a temporary library. For static analysis, it contains the harmonic force vectors and the corresponding static displacements. For eigenvalue analysis, it contains the harmonic eigenvectors and eigenvalues. These vectors correspond to the symmetrical components of applied load and motion that are defined in section 1.1. Subject to user control, LIB6 may be stored as a LIBLIB data set in LIB5. See sections 2.1.4 and 2.2.4 for the appropriate options. |

As discussed above, the library LIB2 is created for each harmonic solution. LIB2 contains the harmonic stiffness matrix, factored stiffness matrix, mass matrix, etc. For the k -th harmonic solution, the data set KLIB HARM k , if present in LIB4, is retrieved via DCU/RETRIEVE as LIB2, and the contained matrices are used. If KLIB HARM k is not present in LIB4, the required matrices are constructed and stored in LIB2. Subsequently, if the optional register KSAV =1, LIB2 is stored via DCU/STORE as KLIB HARM k in LIB4. In default, KSAV =1, see sections 2.1.4 and 2.2.4.

If the optional register QSAV =1, the data set QLIB HARM k is stored in LIB5 via the DCU/STORE command. k is a circumferential harmonic number. For static solutions, QLIB HARM k contains the symmetrical components of applied loads and motion. For vibrational and buckling analysis, QLIB HARM k contains the eigenvalues and the symmetrical components of the eigenvectors. In default QLIB HARM k is not stored, see sections 2.1.4 and 2.2.4.

3.1.1 CS: OUTPUT DATA SETS

In the following, nbse is the number of sectors for which solution vectors are computed, as specified via the data set BACK SECTORS. The value assigned to the register SET is represented by "set" in the following. See Sections 2.1.1, 2.1.2, and 2.1.3.

STATIC ANALYSIS

For cyclic symmetry models with no plane of reflective symmetry, the following data sets are output to LIB5. If preload is present, ncon=2. With no preload, ncon=1. Registers LIB5, LIB6, SET, and QSAV are discussed in Section 2.1.4.

| <u>Data Set Name</u> | <u>Contents</u> |
|--------------------------------------|---|
| SECT BACK set 1 | (S1,S2,—S1—Snbse),NJ=nbse. Sector Numbers. |
| STAT DISP set ncon | NBLOCKS= nbse Block i is the displacement vector for sector S1, the i-th entry in SECT BACK set. |
| CASE TITL set 1 | Blocked case title data set for use by ES. |
| QLIB HARM set k1 QLIB HARM set k2 | LIBLIB data sets created from LIB6 for each harmonic solution. These data sets are stored only if the register QSAV=1. k1, k2, etc., are harmonic numbers. The content of these data sets is discussed below. |

If the data set STAT DISP set ncon is present in LIB5 at the beginning of the static analysis, the newly computed harmonic components are added to the existing data set.

For each harmonic solution, the library LIB6 is used for storage of harmonic force and displacement arrays. For the k-th harmonic solution, LIB6 will contain the following data sets:

| <u>Data Set Name</u> | <u>Contents</u> |
|----------------------|--|
| APPL FORC set 1 | The harmonic force vector, Eq. 8, Section. 6. |
| STAT DISP set ncon | The harmonic displacement vector, Eq. 8, Section 6. |
| UC AUS set ncon | The cosine component of STAT DISP set ncon. Q_{kc} of Eq. 2, Section 1.1 |
| US AUS set ncon | The sine component of STAT DISP set ncon. Q_{ks} or Eq. 2, Section 1.1. This data set is not present for k=0 or k=n/2, where n is the total number of sectors in the complete structure. |

VIBRATIONAL AND BUCKLING ANALYSES

For vibrational and buckling analysis of cyclic symmetry models with no plane of reflective symmetry, the data sets tabulated below are output to LIB5.

REGISTERS:

NCON=ncon = 1, if preload is not present.
 = 2, if preload is present.
LIB5 = Solution Library, see section 2.10.
LIB6 = Harmonic working Library, see section 2.10.
QSAV = Control register, see section 2.1.4.
PROB = 'VIBR, for vibrational analysis.
 = 'BUCK, for buckling analysis.
k = Specific circumferential harmonic value.
NVECTORS = Number of sector eigenvectors, see section 2.1.4.
NEVALS = Number of retained eigenvalues, see section 2.1.4.

| <u>Data Set Name</u> | | | <u>Contents</u> |
|----------------------|---|---|---|
| EVAL HARM | 1 | 1 | (K1, K2,--- Kn), Circumferential Harmonic Values. |
| EVAL MATR | 1 | 1 | $\begin{bmatrix} W11 & W12 & \text{---} & W1n \\ W21 & W22 & \text{---} & W2n \\ Wm1 & Wm2 & \text{---} & Wmn \end{bmatrix}$ Wij= Eigenvalue corresponding to the ith mode of harmonic Kj. NI= "NEVALS". |
| PREV MATR | 1 | 1 | Matrix of eigenvalues from the next-to-last EIG iteration. Same format as (EVAL MATR 1 1). |
| CONV MATR | 1 | 1 | Eigenvalue convergence matrix = (EVAL-PREV)/EVAL. |
| HZ MATR | 1 | 1 | EVAL MATR 1 1 converted to HZ units. Present only if PROB = 'VIBR. |

The following data sets are produced for each circumferential harmonic $k=k_1, k_2, \dots, k_n$.

| | | | |
|-------------|---|-------|---|
| "PROB" EVAL | k | ncon | (W1, W2, ---), Eigenvalues, NJ= NEVALS. |
| "PROB" PREV | k | ncon | (W1, W2, ---), Eigenvalues from the next-to-last EIG iteration, NJ= NEVALS. |
| SECT BACK | k | 0 | (S1, S2, --- Snbse), NJ= nbse. Sector numbers, see below. |
| "PROB" MODE | k | S1 | Eigenvectors for sector S1, NBLOCKS= NVECTORS. |
| "PROB" MODE | k | S2 | Eigenvectors for sector S2. |
| - - - | | | |
| "PROB" MODE | k | Snbse | Eigenvectors for sector Snbse. |
| QLIB HARM | k | k | LIBLIB data set created from LIB6. This data set is produced only if register QSAV =1, see section 2.1.4. |

For the k -th harmonic solution, LIB6 contains the following data sets:

| <u>Data Set Name</u> | | | <u>Contents</u> | |
|----------------------|-----|------|--|--|
| "PROB" EVAL | k | ncon | Eigenvalues | |
| "PROB" PREV | k | ncon | Eigenvalues of the next-to-last EIG iteration. | |
| "PROB" MODE | k | ncon | Harmonic eigenvectors, see section 6. | |
| UC | AUS | k | ncon | Cosine components of eigenvectors. Q_{kc} of Eq. 2, section 1.1. |
| US | AUS | k | ncon | Sine components of eigenvectors. Q_{ks} of Eq. 2, section 1.1. This data set is not present if $k=0$ or $k= n/2$; $n=$ number of total sectors. |

3.1.2 CS: PRINTED OUTPUT

As discussed in Section 2.1.4, the printed output for cyclic symmetry models with no plane of reflective symmetry is controlled by the user through the optional registers !VPRT and !ES. For static analysis, sector displacements and element stresses are printed. For vibrational and buckling analyses, the printout consists of eigenvectors and tables of eigenvalues, frequencies, and convergence characteristics. Printout is produced only for those sectors named in the input data set (BACK SECTORS), see Sections 2.1.1 through 2.1.3. All printout is appropriately labeled according to sector number and circumferential harmonic number.

Several examples of printout follow.

CS: DISPLACEMENT VECTOR PRINTOUT

STATIC DISPLACEMENTS, SECTOR 1.

ID= 1/ 1/ 1

EDGE LOADING, CONICAL SHELL, CYCLIC SYMMETRY MODEL

| JOINT | 1 | 2 | 3 | 4 | 5 | 6 |
|-------|----------|---------|----------|----------|---------|----------|
| 1 | -.782-04 | .142-08 | .516-05 | -.540-05 | .600-04 | .330-05 |
| 2 | -.772-04 | .125-04 | .510-05 | .726-06 | .593-04 | -.518-06 |
| 3 | -.724-04 | .128-08 | .221-05 | -.469-05 | .738-04 | .268-05 |
| 4 | -.715-04 | .111-04 | .219-05 | .110-05 | .729-04 | -.151-05 |
| 5 | -.651-04 | .116-08 | -.961-06 | -.342-05 | .761-04 | .200-05 |
| 6 | -.643-04 | .986-05 | -.949-06 | .240-05 | .751-04 | -.173-05 |
| 7 | -.587-04 | .103-08 | -.320-05 | -.249-05 | .610-04 | .144-05 |
| 8 | -.579-04 | .874-05 | -.316-05 | .318-05 | .602-04 | -.202-05 |
| 9 | -.529-04 | .908-09 | -.474-05 | -.201-05 | .544-04 | .116-05 |
| 10 | -.523-04 | .773-05 | -.468-05 | .340-05 | .537-04 | -.212-05 |

VIBRATIONAL MODE.

ID= 5/ 1/ 1

SECTOR 1, HARMONIC 5.

EIGENVALUE= .3428324+08, FREQ= 931.8823 HZ

| JOINT | 1 | 2 | 3 | 4 | 5 | 6 |
|-------|----------|----------|----------|----------|---------|---------|
| 1 | -.457+02 | -.161+02 | .000 | .000 | .000 | .425+02 |
| 2 | -.929+02 | -.531+01 | .000 | .000 | .000 | .140+02 |
| 3 | -.451+02 | -.159+02 | -.451+00 | -.576+00 | .231+01 | .420+02 |
| 4 | -.917+02 | -.524+01 | -.916+00 | .743-01 | .479+01 | .138+02 |
| 5 | -.435+02 | -.153+02 | -.891+00 | -.133+01 | .462+01 | .404+02 |
| 6 | -.883+02 | -.505+01 | -.181+01 | -.486-01 | .947+01 | .133+02 |
| 7 | -.407+02 | -.143+02 | -.131+01 | -.212+01 | .683+01 | .379+02 |
| 8 | -.828+02 | -.473+01 | -.266+01 | -.275+00 | .139+02 | .125+02 |
| 9 | -.370+02 | -.130+02 | -.169+01 | -.287+01 | .886+01 | .344+02 |
| 10 | -.751+02 | -.429+01 | -.344+01 | -.542+00 | .180+02 | .113+02 |

BUCKLING MODE.

ID= 6/ 1/ 1

SECTOR 1, HARMONIC 6.

EIGENVALUE= .1933858+03

| JOINT | 1 | 2 | 3 | 4 | 5 | 6 |
|-------|---------|----------|---------|----------|----------|----------|
| 1 | .271+00 | .537-02 | .000 | .000 | .000 | -.205-01 |
| 2 | .187+00 | -.310-01 | .000 | .000 | .000 | .119+00 |
| 3 | .268+00 | .530-02 | .234-02 | -.542-03 | -.143-01 | -.203-01 |
| 4 | .185+00 | -.306-01 | .162-02 | -.199-02 | -.998-02 | .117+00 |
| 5 | .258+00 | .510-02 | .463-02 | -.577-03 | -.282-01 | -.195-01 |
| 6 | .178+00 | -.294-01 | .320-02 | -.385-02 | -.196-01 | .113+00 |
| 7 | .241+00 | .478-02 | .680-02 | -.354-03 | -.415-01 | -.183-01 |
| 8 | .167+00 | -.276-01 | .470-02 | -.547-02 | -.287-01 | .106+00 |
| 9 | .219+00 | .434-02 | .881-02 | -.233-04 | -.537-01 | -.166-01 |
| 10 | .151+00 | -.251-01 | .608-02 | -.687-02 | -.371-01 | .960-01 |

CS: ELEMENT STRESS PRINTOUT

PAGE 1 CYCLIC SYMMETRY, ELEMENT STRESSES, SECTOR 4
S/C 1/ 2 EDGE LOADING, CONICAL SHELL, CYCLIC SYMMETRY MODEL
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GRP-IND*/

| JOINTS | | NX | NY | NXY | ANG | MAX PN | MIN PN | MAX SHR |
|--------|-----|----------|---------|----------|------|---------|----------|---------|
| 1- | 1* | .545-01 | .152+00 | -.950+00 | 134. | .105+01 | -.848+00 | .951+00 |
| 1- | 2* | -.153-01 | .386+00 | -.791+00 | 128. | .100+01 | -.631+00 | .816+00 |
| 1- | 3* | -.175-02 | .546+00 | -.670+00 | 124. | .996+00 | -.452+00 | .724+00 |
| 1- | 4* | -.125-02 | .656+00 | -.574+00 | 120. | .989+00 | -.334+00 | .662+00 |
| 1- | 5* | -.219-02 | .731+00 | -.498+00 | 117. | .983+00 | -.254+00 | .618+00 |
| 1- | 6* | -.177-02 | .782+00 | -.436+00 | 114. | .976+00 | -.196+00 | .586+00 |
| 1- | 7* | -.162-02 | .816+00 | -.385+00 | 112. | .968+00 | -.154+00 | .561+00 |
| 1- | 8* | -.151-02 | .837+00 | -.342+00 | 110. | .959+00 | -.123+00 | .541+00 |
| 1- | 9* | -.138-02 | .849+00 | -.306+00 | 108. | .947+00 | -.100+00 | .524+00 |
| 1- | 10* | -.127-02 | .854+00 | -.275+00 | 106. | .935+00 | -.823-01 | .509+00 |
| 1- | 11* | -.118-02 | .854+00 | -.249+00 | 105. | .921+00 | -.686-01 | .495+00 |
| 1- | 12* | -.107-02 | .850+00 | -.227+00 | 104. | .907+00 | -.577-01 | .482+00 |

PAGE 1 CYCLIC SYMMETRY, ELEMENT STRESSES, SECTOR 1
S/C 1/ 1 RAIL WHEEL EXAMPLE
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STRESSES

| GRP-IND* | JOINT | ONS | OSS | SI | SYR |
|----------|---------|----------|---------|---------|------|
| 1/ | 1* MID | .402+03 | .111+04 | .257+04 | .000 |
| 1/ | 2* MID | -.120+03 | .453+03 | .102+04 | .000 |
| 1/ | 3* MID | .221+04 | .160+04 | .393+04 | .000 |
| 1/ | 4* MID | -.974+03 | .126+04 | .301+04 | .000 |
| 1/ | 5* MID | .930+03 | .903+03 | .200+04 | .000 |
| 1/ | 6* MID | .837+02 | .405+03 | .991+03 | .000 |
| 1/ | 7* MID | .597+03 | .431+03 | .931+03 | .000 |
| 1/ | 8* MID | .840+02 | .184+03 | .446+03 | .000 |
| 1/ | 9* MID | .954+02 | .116+03 | .281+03 | .000 |
| 1/ | 10* MID | .115+03 | .250+03 | .600+03 | .000 |
| 1/ | 11* MID | -.294+03 | .306+03 | .742+03 | .000 |
| 1/ | 12* MID | .166+03 | .322+03 | .767+03 | .000 |

CS: VIBRATIONAL EIGENVALUE PRINTOUT

CYCLIC SYMMETRY VIBRATIONAL EIGENVALUES FOLLOW:

| MODE | HARMONIC NUMBER | EIGENVALUE | HZ |
|------|--------------------|------------|----------|
| 1 | 1 | .7508+07 | 436.11 |
| 2 | 1 | .7508+07 | 436.11 |
| 3 | 2 | .2289+08 | 761.52 |
| 4 | 2 | .2289+08 | 761.52 |
| 5 | 0 | .2386+08 | 777.35 |
| 6 | 0 | .4922+08 | 1116.57 |
| 7 | 3 | .1096+09 | 1666.33 |
| 8 | 3 | .1096+09 | 1666.33 |
| 9 | 1 | .1161+09 | 1714.57 |
| 10 | 1 | .1161+09 | 1714.57 |
| 11 | 2 | .1803+09 | 2137.32 |
| 12 | 2 | .1803+09 | 2137.32 |
| 13 | 4 | .2572+09 | 2552.20 |
| 14 | 4 | .2572+09 | 2552.30 |
| 15 | 0 | .3257+09 | 2872.42 |
| 16 | 3 | .3730+09 | 3073.97 |
| 17 | 3 | .3730+09 | 3073.97 |
| 18 | 1 | .4745+09 | 3466.83 |
| 19 | 1 | .4745+09 | 3466.88 |
| 20 | 3 | .4854+09 | 3506.62 |
| 21 | 3 | .4855+09 | 3506.72 |
| 22 | 0 | .6275+09 | 3986.69 |
| 23 | 4 | .8122+09 | 4535.66 |
| 24 | 4 | .8153+09 | 4544.35 |
| 25 | 2 | .8308+09 | 4587.40 |
| 26 | 2 | .8362+09 | 4602.38 |
| 27 | 2 | .8433+09 | 4621.87 |
| 28 | 2 | .8483+09 | 4635.51 |
| 29 | 1 | .8637+09 | 4677.27 |
| 30 | 1 | .8669+09 | 4685.97 |
| 31 | 2 | .1162+10 | 5424.33 |
| 32 | 3 | .1224+10 | 5568.93 |
| 33 | 1 | .1338+10 | 5821.83 |
| 34 | 1 | .1366+10 | 5883.15 |
| 35 | 3 | .1403+10 | 5962.37 |
| 36 | 0 | .1426+10 | 6010.39 |
| 37 | 3 | .1548+10 | 6261.61 |
| 38 | 4 | .1755+10 | 6668.14 |
| 39 | 4 | .1778+10 | 6710.19 |
| 40 | 3 | .1874+10 | 6889.51 |
| 41 | 0 | .2057+10 | 7218.62 |
| 42 | 0 | .2057+10 | 7218.84 |
| 43 | 2 | .2389+10 | 7778.75 |
| 44 | 4 | .2670+10 | 8223.40 |
| 45 | 4 | .2693+10 | 8258.71 |
| 46 | 0 | .3371+10 | 9240.64 |
| 47 | 0 | .3684+10 | 9659.75 |
| 48 | 4 | .4469+10 | 10639.18 |

CS: VIBRATIONAL EIGENVALUE PRINTOUT, (cont.)

VIBRATIONAL FREQUENCIES, HZ

| HARMONICS: | | | | | |
|------------|---------|---------|---------|---------|---------|
| MODE | 0 | 1 | 2 | 3 | 4 |
| 1 | .777+03 | .436+03 | .762+03 | .167+04 | .255+04 |
| 2 | .112+04 | .436+03 | .762+03 | .167+04 | .255+04 |
| 3 | .287+04 | .171+04 | .214+04 | .307+04 | .454+04 |
| 4 | .399+04 | .171+04 | .214+04 | .307+04 | .454+04 |
| 5 | .601+04 | .347+04 | .459+04 | .351+04 | .667+04 |
| 6 | .722+04 | .347+04 | .460+04 | .351+04 | .671+04 |
| 7 | .722+04 | .468+04 | .462+04 | .557+04 | .822+04 |
| 8 | .924+04 | .469+04 | .464+04 | .596+04 | .826+04 |
| 9 | .966+04 | .582+04 | .542+04 | .626+04 | .106+05 |
| 10 | .122+05 | .588+04 | .778+04 | .689+04 | .119+05 |

EIGENVALUES

| HARMONICS: | | | | | |
|------------|---------|---------|---------|---------|---------|
| MODE | 0 | 1 | 2 | 3 | 4 |
| 1 | .239+08 | .751+07 | .229+08 | .110+09 | .257+09 |
| 2 | .492+08 | .751+07 | .229+08 | .110+09 | .257+09 |
| 3 | .326+09 | .116+09 | .180+09 | .373+09 | .812+09 |
| 4 | .627+09 | .116+09 | .180+09 | .373+09 | .815+09 |
| 5 | .143+10 | .474+09 | .831+09 | .485+09 | .176+10 |
| 6 | .206+10 | .474+09 | .836+09 | .485+09 | .178+10 |
| 7 | .206+10 | .864+09 | .843+09 | .122+10 | .267+10 |
| 8 | .337+10 | .867+09 | .848+09 | .140+10 | .269+10 |
| 9 | .368+10 | .134+10 | .116+10 | .155+10 | .447+10 |
| 10 | .591+10 | .137+10 | .239+10 | .187+10 | .561+10 |

EIGENVALUE CONVERGENCE MATRIX

| HARMONICS: | | | | | |
|------------|----------|----------|----------|----------|----------|
| MODE | 0 | 1 | 2 | 3 | 4 |
| 1 | .000 | .000 | .000 | -.912-08 | .000 |
| 2 | .000 | .000 | .000 | -.912-08 | .000 |
| 3 | -.123-07 | .000 | -.111-07 | -.429-07 | -.493-07 |
| 4 | -.892-07 | .000 | .000 | -.168-04 | -.196-07 |
| 5 | -.238-04 | -.814-05 | -.150-04 | -.659-05 | -.506-03 |
| 6 | -.579-04 | -.211-03 | -.222-02 | -.391-03 | -.133-04 |
| 7 | -.391-03 | -.317-03 | -.815-04 | -.425-02 | -.355-02 |
| 8 | -.669-02 | -.544-02 | -.929-02 | -.278-01 | -.141-02 |
| 9 | -.404-01 | -.175-02 | -.353-02 | -.257-01 | -.169-02 |
| 10 | -.459-01 | -.490-02 | -.883-02 | -.576-01 | -.195+00 |

The EIGENVALUE CONVERGENCE MATRIX is computed as $(E-P)/E$, where

E= matrix of eigenvalues, and

P= matrix of eigenvalues from the next-to-last EIG iteration.

CS: BUCKLING EIGENVALUE PRINTOUT

CYCLIC SYMMETRY BUCKLING EIGENVALUES FOLLOW:

| MODE | HARMONIC NUMBER | EIGENVALUE |
|------|--------------------|------------|
| 1 | 8 | .1089+03 |
| 2 | 8 | .1089+03 |
| 3 | 9 | .1105+03 |
| 4 | 9 | .1105+03 |
| 5 | 7 | .1270+03 |
| 6 | 7 | .1270+03 |
| 7 | 6 | .1934+03 |
| 8 | 6 | .1934+03 |
| 9 | 9 | .7415+03 |
| 10 | 9 | .7426+03 |
| 11 | 8 | .9631+03 |
| 12 | 8 | .9682+03 |
| 13 | 7 | .1340+04 |
| 14 | 7 | .1372+04 |
| 15 | 6 | .2020+04 |
| 16 | 6 | .2130+04 |

EIGENVALUES

| MODE | HARMONICS: | | | |
|------|------------|---------|---------|---------|
| | 6 | 7 | 8 | 9 |
| 1 | .193+03 | .127+03 | .109+03 | .110+03 |
| 2 | .193+03 | .127+03 | .109+03 | .110+03 |
| 3 | .202+04 | .134+04 | .963+03 | .741+03 |
| 4 | .213+04 | .137+04 | .968+03 | .743+03 |

EIGENVALUE CONVERGENCE MATRIX

| MODE | HARMONICS: | | | |
|------|------------|----------|----------|----------|
| | 6 | 7 | 8 | 9 |
| 1 | -.397-05 | -.841-06 | -.709-06 | -.123-05 |
| 2 | -.439-05 | -.916-06 | -.595-06 | -.128-05 |
| 3 | -.298-01 | -.227-01 | -.104-01 | -.540-02 |
| 4 | -.877-02 | -.306-01 | -.172-01 | -.857-02 |

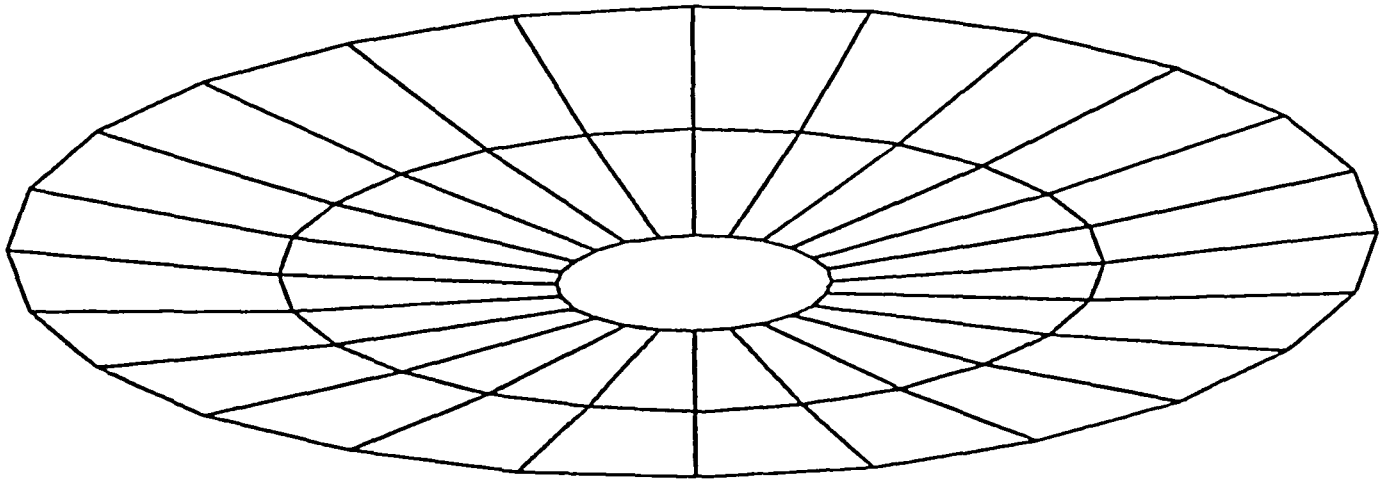
The EIGENVALUE CONVERGENCE MATRIX is computed as $(E-P)/E$, where

E= matrix of eigenvalues, and

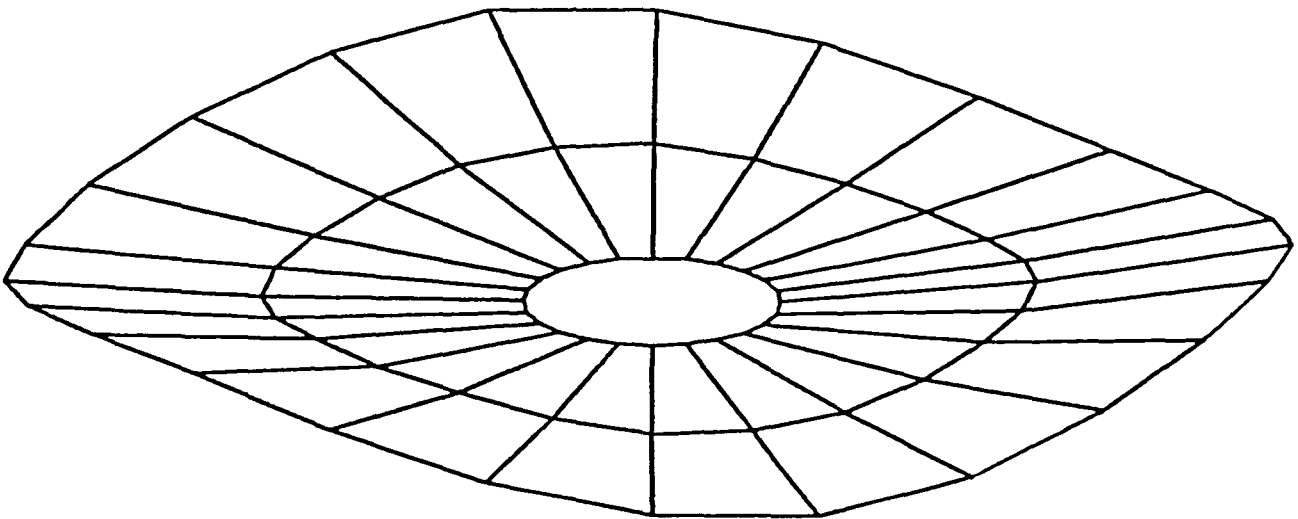
P= matrix of eigenvalues from the next-to-last EIG iteration.

3.1.3. CS: PLOTTED OUTPUT

The plots shown below are examples of whole structure plots generated from a cyclic symmetry model of one sector. The runstream element CS PLOT was used to construct plots.



Undeformed Structure



Deformed Structure

Instructions for using CS PLOT are given on the following two pages.

The runstream element (CS PLOT) may be used to produce a pseudo model of the entire structure for purposes of generating undeformed and deformed plots of the entire assemblage of cyclically symmetrical sectors. For undeformed plots, it is necessary that "LIB1" from the (CS) execution be attached as Library 1. For deformed plots (static displacements, vibrational modes, or buckling modes), it is necessary that "LIB5" be attached as Library 5. See section 2.10 for descriptions of library contents. Data sets characterizing the pseudo model are inserted into EAL Library 2 by (CS PLOT).

Given a list of joint numbers which are a subset of the joints in the CS model, (CS PLOT) produces data sets containing joint locations and specified displacement vectors for the pseudo model. Plot specifications for the pseudo model are supplied by the user through LINES and/or CONNECT commands in PLTA. PLTB is then used to construct the required plots.

To plot the entire assemblage of cyclically symmetrical sectors, proceed as follows:

*XQT AUS
OUTLIB=2

The following data set resides in Lib 2.

TABLE(NJ=njt, TYPE=0):JLIST
J=1,njt: j1: j2:---

j1, j2,---is a list of joints from the CS model to include in the pseudo model. The total number of joints in the pseudo model will be (njt x NSECTORS). Joint 1 of the psuedo model is j1 of sector 1; joint 2 is j2 of sector 1; joint (njt+1) is j1 of sector 2; etc.

*XQT U1

*(PLOT OPTIONS)

!PROB = 'UNDEFORMED
= 'STAT
= 'VIBR
= 'BUCK

For undeformed plots only, no displacement vectors.
For static displacement vectors,
For vibrational modes,
For buckling modes,
Default is !PROB='VIBR.

!SET = set
!CON = con

If !PROB='STAT, set and con are the static solution set number and constraint condition. Default is set=1, con=1. For other !PROB values, SET and CON are not used.

*XQT AUS
OUTLIB=2

The following data set resides in Lib 2.

TABLE(NJ=n, TYPE=0):HARMONICS
J=1,n: k1: k2:---

If !PROB='VIBR or 'BUCK, model vectors for the pseudo model are to be produced for harmonics k1, k2,---. For !PROB='UNDE or 'STAT, this data set is not required.

*CALL (CS PLOT 1 1)

Generate the pseudo model joint locations and the required displacement vectors.

*XQT PLTA

SPEC 1

LINES and/or CONNECT commands. Pseudo model plot specifications are defined through these commands. Note that joint 1 of the pseudo model is j1 of the data set JLIST; joint 2 is j2, etc.

*XQT PLTB

Plot the required specs.

Note that no element definitions are generated for the pseudo model, only joint locations and displacement vectors. Consequently, all plot specifications consist of user supplied LINES and/or CONNECT commands. See the Volume 1 of the EAL Reference Manual for a discussion of these commands.

3.2.1 CSR: OUTPUT DATA SETS

The output data sets produced by CSR for cyclic symmetry models with a plane of reflective symmetry are summarized in this section. The registers LIB1, LIB5, LIB6, set, CONS, CONA, NVECTORS, NEVALS, and QSAV are discussed in section 2.2.4. Values assigned to registers CONS and CONA are represented by "cons" and "cona", respectively. The value assigned to SET is represented by "set".

The following data sets are output to LIB1.

| <u>Data Set Name</u> | | | | <u>Contents</u> |
|----------------------|------|---|--|---|
| CON | cons | 0 | | The active constraint plus symmetric constraint on the reflective plane. |
| CON | cona | 0 | | The active constraint plus anti-symmetric constraint on the reflective plane. |

If data set (CON "CONS" 0) and (CON "CONA" 0) reside in LIB1 at the beginning of the analysis, no new CON data sets will be produced.

In the following, nbsc is the number of sectors for which solution vectors are computed, as specified via the data set BACK SECTORS, See Sections 2.2.1, 2.2.2, and 2.2.3.

STATIC ANALYSIS

For static analysis, the following data sets are output to LIB5:

| <u>Data Set Name</u> | | | | <u>Contents</u> |
|----------------------|------|-----|----|--|
| SECT | BACK | set | 1 | (S1,S2---S1---Snbsc),NJ=nbsc |
| U+ | DISP | set | 1 | NBLOCKS=nbsc. Block 1 is the displacement vector for the +side of sector S1, the ith entry in SECT BACK set 1. |
| U- | DISP | set | 1 | NBLOCKS=nbsc. Block 1 is the displacement vector for the -side of sector S1, the ith entry in SECT BACK set 1. |
| CASE | TITL | set | 1 | Blocked case title data set for use with ES. |
| QLIB | HARM | set | k1 | LIBLIB data sets created from LIB6 for each harmonic solution. These data sets are stored only if the register QSAV =1. k1, k2, etc. are harmonic numbers. The contents of the data sets is discussed below. |
| QLIB | HARM | set | k2 | |
| - - - | | | | |

Note that the -side displacement vectors stored in U- DISP set 1 are relative to left handed joint reference frames, see Fig. 4.

If U+ DISP set 1 and U- DISP set 1 reside in LIB5 at the beginning of the static analysis, the newly computed harmonic components are added to the existing data sets.

For each harmonic solution, the library LIB6 is used for storage of the harmonic force and displacement arrays. For the k-th harmonic solution, LIB6 will contain the following data sets:

| <u>Data Set Name</u> | | | | <u>Contents</u> |
|----------------------|------|---|---|--|
| APPL | FORC | 1 | 1 | Force and displacement vectors, first harmonic solution, Eq. 28, section 6. |
| STAT | DISP | 1 | 1 | |
| APPL | FORC | 2 | 1 | Force and displacement vectors, second harmonic solution, Eq. 29, section 6. |
| STAT | DISP | 2 | 2 | |
| QCA | AUS | k | 1 | The anti-symmetric cosine component of the solution, Q_{kc}^a of Eq. 9, section 1.1. |
| QCS | AUS | k | 1 | The symmetric cosine component of the solution, Q_{kc}^s of Eq. 10, section 1.1. |
| QSA | AUS | k | 1 | The anti-symmetric sine component of the solution, Q_{ks}^a of Eq. 9, section 1.1. |
| QSS | AUS | k | 1 | The symmetric sine component of the solution, Q_{ks}^s of Eq. 10, section 1.1. |

Data sets QSA AUS k 1 and QSS AUS k 1 are not present in LIB6 for k=0 or k=n/2, where n= number of sectors in the complete structure.

VIBRATIONAL AND BUCKLING ANALYSES

For vibrational and buckling analyses of cyclic symmetry models with a plane of reflective symmetry, the data sets tabulated below are output to LIB5.

| <u>Data Set Name</u> | | | | <u>Contents</u> |
|----------------------|--|--|--|--|
| EVAL HARM 1 1 | | | | (k1, k2,---kn) , Circumferential Harmonic Values. |
| S-EV MATR 1 1 | | | | $\begin{bmatrix} W_{11} & W_{12} & \cdots & W_{1n} \\ W_{21} & W_{22} & \cdots & W_{2n} \\ - & - & - & - \\ W_{m1} & W_{m2} & \cdots & W_{mn} \end{bmatrix}$, Wij= eigenvalue corresponding to the ith mode of harmonic kj, with symmetric constraints on the reflective plane. NI= NEVALS. |
| S-PR MATR 1 1 | | | | Matrix of eigenvalues from the next-to-last EIG iteration. Same format as S-EV MATR 1 1. |
| S-CO MATR 1 1 | | | | Eigenvalue convergence matrix computed as ((S-EV)- (S-PR))/(S-EV). |
| S-HZ MATR 1 1 | | | | S-EV MATR 1 1 converted to HZ units. Present only if PROB= 'VIBR. |
| A-EV MATR 1 1 | | | | Eigenvalue matrices corresponding to anti-symmetric constraints on the reflective plane. Formats and content are the same as (S-EV), (S-PR), (S-CO), and (S-HZ). |
| A-PR MATR 1 1 | | | | |
| A-CO MATR 1 1 | | | | |
| A-HZ MATR 1 1 | | | | |

The following data sets are output to LIB5 for each circumferential harmonic k=k1, k2,---kn. Data sets with a first word of SYM correspond to symmetric reflective eigensolutions. Data sets with a first word of ASYM correspond to anti-symmetric reflective eigensolutions.

| <u>Data Set Name</u> | | | | <u>Contents</u> |
|----------------------|--|--|--|---|
| SECT BACK k 0 | | | | (S1, S2,---Snbsc),NJ=nbsc |
| SYM EVAL k cons | | | | (W1, W2,---),Eigenvalues, NJ= NEVALS |
| SYM PREV k cons | | | | (W1, W2,---),Eigenvalues, next-to-last EIG iteration. |
| SYM MODE k S1 | | | | Eigenvectors, Sector S1, Symmetric Motion, NBLOCKS= NVECTORS. |
| SYM MODE k S2 | | | | Eigenvectors, Sector S2, Symmetric motion. |
| - - - | | | | |
| SYM MODE k Snbsc | | | | Eigenvectors, Sector Snbsc, Symmetric motion. |

| <u>Data Set Name</u> | | | | <u>Contents</u> |
|----------------------|------|---|-------|--|
| ASYM | EVAL | k | cona | (W1, W1---), Eigenvalues, NJ= NVECTORS. |
| ASYM | PRE | k | cona | (W1, W2---), Eigenvalues, next-to-last EIG iteration. |
| ASYM | MODE | k | S1 | Eigenvectors, Sector S1, Anti-Symmetric Motion, NBLOCKS= NVECTORS. |
| ASYM | MODE | k | S2 | Eigenvectors, Sector S2, Anti-Symmetric Motion. |
| ASYM | MODE | k | Snbsc | Eigenvectors, Sector Snbsc, Anti-Symmetric Motion. |
| - - - | | | | |
| QLIB | HARM | k | k | LIBLIB data set created from LIB6. This data set is stored only if the register QSAV=1. The contents of this data set are discussed below. |

For the k-th harmonic solution, LIB6 will contain the following data sets:

| <u>Data Set Name</u> | | | | <u>Contents</u> |
|----------------------|------|---|---|---|
| "PROB" | EVAL | k | 1 | Eigenvalues and eigenvectors, first harmonic solution, see section 6. |
| "PROB" | PREV | k | 1 | |
| "PROB" | MODE | k | 1 | |
| "PROB" | EVAL | k | 2 | Eigenvalues and eigenvectors, second harmonic solution, see section 6. |
| "PROB" | PREV | k | 2 | |
| "PROB" | MODE | k | 2 | |
| QCA | AUS | k | 1 | The anti-symmetric cosine components of the eigenvectors. Q_{kc}^a of Eq. 9, section 1.1. |
| QCS | AUS | k | 1 | The symmetric cosine components of the eigenvectors. Q_{kc}^s of Eq. 10, section 1.1. |
| QSA | AUS | k | 1 | The anti-symmetric sine components of the eigenvectors. Q_{ks}^a of Eq. 9, section 1.1. |
| QSS | AUS | k | 1 | The symmetric sine components of the eigenvectors. Q_{ks}^s of Eq. 10, section 1.1. |

Data sets QSA AUS k 1 and QSS AUS k 1 are not present on LIB6 for k=0, or k= n/2; n= number of sectors in the complete model.

3.2.2 CSR: PRINTED OUTPUT

As discussed in Section 2.2.4, the printed output for cyclic symmetry models with a plane of reflective symmetry is controlled by the user through optional registers !VPRT and !ES. For static analysis, sector displacements and element stresses are printed. For vibrational and buckling analyses, the printout consists of eigenvectors and tables of eigenvalues, frequencies, and convergence characteristics. Printout is produced only for those sectors named in the input data set (BACK SECTORS), see Sections 2.2.1 through 2.2.3. All printout is appropriately labeled according to sector number, sector side (+ or -), and circumferential harmonic number. Eigenvectors are labeled according to the boundary condition (symmetry or anti-symmetry) imposed on the reflective symmetry plane.

Several examples of printout follow.

CSR: DISPLACEMENT VECTOR PRINTOUT

SECTOR 6, +SIDE DISPLACEMENTS.

ID= 1/ 1/ 4

EDGE LOADING, CONICAL SHELL, CYCLIC SYMMETRY MODEL

| JOINT | 1 | 2 | 3 | 4 | 5 | 6 |
|-------|----------|---------|----------|---------|----------|----------|
| 1 | -.122-04 | .783-04 | .803-06 | .400-04 | .939-05 | -.249-04 |
| 2 | .690-09 | .793-04 | -.455-10 | .405-04 | -.527-09 | -.253-04 |
| 3 | -.113-04 | .697-04 | .344-06 | .382-04 | .115-04 | -.273-04 |
| 4 | .640-09 | .705-04 | -.196-10 | .389-04 | -.652-09 | -.278-04 |
| 5 | -.101-04 | .619-04 | -.149-06 | .384-04 | .118-04 | -.245-04 |
| 6 | .575-09 | .626-04 | .849-11 | .395-04 | -.672-09 | -.252-04 |

SECTOR 6, -SIDE DISPLACEMENTS.

ID= 1/ 1/ 4

EDGE LOADING, CONICAL SHELL, CYCLIC SYMMETRY MODEL

| JOINT | 1 | 2 | 3 | 4 | 5 | 6 |
|-------|---------|----------|----------|----------|----------|---------|
| 1 | .122-04 | -.783-04 | -.803-06 | -.400-04 | -.939-05 | .249-04 |
| 2 | .690-09 | -.793-04 | -.455-10 | -.405-04 | -.527-09 | .253-04 |
| 3 | .113-04 | -.697-04 | -.344-06 | -.382-04 | -.115-04 | .273-04 |
| 4 | .640-09 | -.705-04 | -.196-10 | -.389-04 | -.652-09 | .278-04 |
| 5 | .101-04 | -.619-04 | .149-06 | -.384-04 | -.118-04 | .245-04 |
| 6 | .575-09 | -.626-04 | .849-11 | -.395-04 | -.672-09 | .252-04 |

VIBRATIONAL MODE.

ID= 4/ 1/ 1

SECTOR 1, HARMONIC 4, SYMMETRIC MOTION.

EIGENVALUE= .5629889+08, FREQ= 1194.1807 HZ

| JOINT | 1 | 2 | 3 | 4 | 5 | 6 |
|-------|----------|----------|----------|----------|---------|---------|
| 1 | -.779+02 | -.128+02 | .000 | .000 | .000 | .226+02 |
| 2 | -.963+02 | .000 | .000 | .000 | .000 | .000 |
| 3 | -.769+02 | -.127+02 | -.823+00 | -.802+00 | .394+01 | .224+02 |
| 4 | -.951+02 | .000 | -.102+01 | .000 | .487+01 | .000 |
| 5 | -.741+02 | -.122+02 | -.163+01 | -.148+01 | .778+01 | .215+02 |
| 6 | -.916+02 | .000 | -.201+01 | .000 | .966+01 | .000 |

BUCKLING MODE.

ID= 6/ 1/ 1

SECTOR 1, HARMONIC 6, ANTI-SYMMETRIC MOTION.

EIGENVALUE= .1933798+03

| JOINT | 1 | 2 | 3 | 4 | 5 | 6 |
|-------|----------|---------|----------|---------|---------|----------|
| 1 | -.221+00 | .250-01 | .000 | .000 | .000 | -.959-01 |
| 2 | .000 | .425-01 | .000 | .000 | .000 | -.162+00 |
| 3 | -.218+00 | .247-01 | -.191-02 | .163-02 | .117-01 | -.947-01 |
| 4 | .000 | .420-01 | .000 | .148-02 | .000 | -.160+00 |
| 5 | -.210+00 | .238-01 | -.377-02 | .296-02 | .230-01 | -.912-01 |
| 6 | .000 | .404-01 | .000 | .369-02 | .000 | -.155+00 |

CSR: ELEMENT STRESS PRINTOUT

PAGE 1 CYCLIC SYMMETRY, +SIDE ELEMENT STRESSES, SECTOR 2
S/C 1/ 2 RAIL WHEEL EXAMPLE
S81

| STRESSES | | | | | |
|----------|-------|----------|---------|---------|------|
| GRP-IND* | JOINT | ONS | OSS | SI | SYR |
| 1/ 1* | MID | .220+03 | .902+03 | .215+04 | .000 |
| 1/ 2* | MID | -.223+03 | .552+03 | .133+04 | .000 |
| 1/ 3* | MID | .147+04 | .110+04 | .268+04 | .000 |
| 1/ 4* | MID | -.823+03 | .127+04 | .297+04 | .000 |
| 1/ 5* | MID | .738+03 | .686+03 | .157+04 | .000 |
| 1/ 6* | MID | .139+03 | .591+03 | .143+04 | .000 |
| 1/ 7* | MID | .502+03 | .418+03 | .102+04 | .000 |
| 1/ 8* | MID | -.395+02 | .648+03 | .159+04 | .000 |
| 1/ 9* | MID | .233+03 | .342+03 | .739+03 | .000 |
| 1/ 10* | MID | -.180+03 | .640+03 | .155+04 | .000 |
| 1/ 11* | MID | .326+02 | .409+03 | .100+04 | .000 |
| 1/ 12* | MID | -.309+03 | .640+03 | .149+04 | .000 |

PAGE 1 CYCLIC SYMMETRY, -SIDE ELEMENT STRESSES, SECTOR 2
S/C 1/ 2 RAIL WHEEL EXAMPLE
S81

| STRESSES | | | | | |
|----------|-------|----------|---------|---------|------|
| GRP-IND* | JOINT | ONS | OSS | SI | SYR |
| 1/ 1* | MID | .212+03 | .792+03 | .183+04 | .000 |
| 1/ 2* | MID | .102+03 | .308+03 | .755+03 | .000 |
| 1/ 3* | MID | .156+04 | .112+04 | .273+04 | .000 |
| 1/ 4* | MID | -.206+03 | .109+04 | .265+04 | .000 |
| 1/ 5* | MID | .557+03 | .592+03 | .143+04 | .000 |
| 1/ 6* | MID | .859+02 | .831+03 | .203+04 | .000 |
| 1/ 7* | MID | .429+03 | .387+03 | .931+03 | .000 |
| 1/ 8* | MID | -.706+02 | .691+03 | .169+04 | .000 |
| 1/ 9* | MID | .206+03 | .363+03 | .797+03 | .000 |
| 1/ 10* | MID | -.205+03 | .630+03 | .151+04 | .000 |
| 1/ 11* | MID | .245+02 | .383+03 | .937+03 | .000 |
| 1/ 12* | MID | -.323+03 | .638+03 | .148+04 | .000 |

CSR: VIBRATIONAL EIGENVALUE PRINTOUT

CYCLIC SYMMETRY VIBRATIONAL EIGENVALUES FOLLOW:

| MODE | HARMONIC NUMBER | REFLECTIVE BND. COND. | EIGENVALUE | HZ |
|------|--------------------|--------------------------|------------|---------|
| 1 | 7 | ASYM | .2259+08 | 756.37 |
| 2 | 7 | SYMM | .2259+08 | 756.37 |
| 3 | 6 | ASYM | .2473+08 | 791.48 |
| 4 | 6 | SYMM | .2473+08 | 791.48 |
| 5 | 8 | SYMM | .2567+08 | 806.41 |
| 6 | 8 | ASYM | .2567+08 | 806.41 |
| 7 | 9 | ASYM | .3331+08 | 918.52 |
| 8 | 9 | SYMM | .3331+08 | 918.52 |
| 9 | 5 | SYMM | .3428+08 | 931.86 |
| 10 | 5 | ASYM | .3428+08 | 931.86 |
| 11 | 10 | SYMM | .4558+08 | 1074.46 |
| 12 | 10 | ASYM | .4559+08 | 1074.58 |
| 13 | 4 | ASYM | .5630+08 | 1194.18 |
| 14 | 4 | SYMM | .5630+08 | 1194.18 |
| 15 | 9 | ASYM | .6303+08 | 1263.58 |
| 16 | 9 | SYMM | .6303+08 | 1263.58 |
| 17 | 8 | ASYM | .8648+08 | 1480.05 |
| 18 | 8 | SYMM | .8648+08 | 1480.05 |
| 19 | 7 | ASYM | .1169+09 | 1721.11 |
| 20 | 7 | SYMM | .1169+09 | 1721.11 |
| 21 | 6 | SYMM | .1556+09 | 1985.35 |
| 22 | 6 | ASYM | .1556+09 | 1985.36 |
| 23 | 5 | ASYM | .2038+09 | 2271.98 |
| 24 | 5 | SYMM | .2038+09 | 2272.00 |

VIBRATIONAL FREQUENCIES, HZ
SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

| HARMONICS: | | | | | | | |
|------------|---------|---------|---------|---------|---------|---------|---------|
| MODE | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | .119+04 | .932+03 | .791+03 | .756+03 | .806+03 | .919+03 | .107+04 |
| 2 | .258+04 | .227+04 | .199+04 | .172+04 | .148+04 | .126+04 | .242+04 |
| 3 | .288+04 | .275+04 | .262+04 | .251+04 | .243+04 | .240+04 | .421+04 |
| 4 | .378+04 | .344+04 | .308+04 | .282+04 | .264+04 | .251+04 | .633+04 |

VIBRATIONAL FREQUENCIES, HZ
ANTI-SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

| HARMONICS: | | | | | | | |
|------------|---------|---------|---------|---------|---------|---------|---------|
| MODE | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | .119+04 | .932+03 | .791+03 | .756+03 | .806+03 | .919+03 | .107+04 |
| 2 | .258+04 | .227+04 | .199+04 | .172+04 | .148+04 | .126+04 | .242+04 |
| 3 | .288+04 | .275+04 | .262+04 | .251+04 | .243+04 | .240+04 | .420+04 |
| 4 | .360+04 | .330+04 | .304+04 | .281+04 | .263+04 | .250+04 | .631+04 |

CSR: VIBRATIONAL EIGENVALUE PRINTOUT (cont.)

EIGENVALUES

SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

| HARMONICS: | | | | | | | |
|------------|---------|---------|---------|---------|---------|---------|---------|
| MODE | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | .563+08 | .343+08 | .247+08 | .226+08 | .257+08 | .333+08 | .456+08 |
| 2 | .263+09 | .204+09 | .156+09 | .117+09 | .865+08 | .630+08 | .232+09 |
| 3 | .328+09 | .298+09 | .270+09 | .248+09 | .234+09 | .228+09 | .699+09 |
| 4 | .565+09 | .467+09 | .374+09 | .314+09 | .276+09 | .248+09 | .158+10 |

EIGENVALUE CONVERGENCE MATRIX

SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

| HARMONICS: | | | | | | | |
|------------|----------|----------|----------|----------|----------|----------|----------|
| MODE | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | -.888-08 | -.146-07 | .000 | .000 | .000 | -.600-07 | -.110-07 |
| 2 | -.322-03 | -.128-03 | -.322-04 | -.545-05 | -.379-04 | -.612-05 | -.139-04 |
| 3 | -.354-04 | -.140-04 | -.297-04 | -.134-03 | -.235-02 | -.821-02 | -.239-02 |
| 4 | -.936-02 | -.486-01 | -.440-01 | -.216-01 | -.549-01 | -.541-01 | -.178-01 |

EIGENVALUES

ANTI-SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

| HARMONICS: | | | | | | | |
|------------|---------|---------|---------|---------|---------|---------|---------|
| MODE | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | .563+08 | .343+08 | .247+08 | .226+08 | .257+08 | .333+08 | .456+08 |
| 2 | .263+09 | .204+09 | .156+09 | .117+09 | .865+08 | .630+08 | .232+09 |
| 3 | .328+09 | .298+09 | .270+09 | .248+09 | .233+09 | .228+09 | .698+09 |
| 4 | .513+09 | .430+09 | .364+09 | .311+09 | .273+09 | .247+09 | .157+10 |

EIGENVALUE CONVERGENCE MATRIX

ANTI-SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

| HARMONICS: | | | | | | | |
|------------|----------|----------|----------|----------|----------|----------|----------|
| MODE | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | .000 | .000 | .000 | .000 | .000 | -.195-06 | .000 |
| 2 | -.496-03 | -.480-04 | -.566-04 | -.652-05 | -.342-04 | -.589-05 | -.527-06 |
| 3 | -.770-04 | -.225-04 | -.869-04 | -.134-03 | -.371-02 | -.767-02 | -.296-03 |
| 4 | -.927-03 | -.281-03 | -.166-02 | -.170-02 | -.180-01 | -.309-01 | -.293-02 |

Each EIGENVALUE CONVERGENCE MATRIX is computed as (E-P)/E, where

E= matrix of eigenvalues, and

P= matrix of eigenvalues from the next-to-last EIG iteration.

CSR: BUCKLING EIGENVALUE PRINTOUT

CYCLIC SYMMETRY BUCKLING EIGENVALUES FOLLOW:

| MODE | HARMONIC NUMBER | REFLECTIVE BND. COND. | EIGENVALUE |
|------|--------------------|--------------------------|------------|
| 1 | 8 | SYMM | .1089+03 |
| 2 | 8 | ASYM | .1089+03 |
| 3 | 9 | SYMM | .1105+03 |
| 4 | 9 | ASYM | .1105+03 |
| 5 | 7 | SYMM | .1270+03 |
| 6 | 7 | ASYM | .1270+03 |
| 7 | 9 | ASYM | .1381+03 |
| 8 | 9 | SYMM | .1381+03 |
| 9 | 8 | ASYM | .1584+03 |
| 10 | 8 | SYMM | .1584+03 |
| 11 | 7 | ASYM | .1817+03 |
| 12 | 7 | SYMM | .1817+03 |
| 13 | 6 | ASYM | .1934+03 |
| 14 | 6 | SYMM | .1934+03 |
| 15 | 6 | SYMM | .2076+03 |
| 16 | 6 | ASYM | .2076+03 |
| 17 | 6 | ASYM | .4763+03 |
| 18 | 6 | SYMM | .4764+03 |
| 19 | 7 | ASYM | .4769+03 |
| 20 | 7 | SYMM | .4774+03 |
| 21 | 8 | SYMM | .4943+03 |
| 22 | 8 | ASYM | .4947+03 |
| 23 | 9 | SYMM | .5377+03 |
| 24 | 9 | ASYM | .5439+03 |
| 25 | 9 | SYMM | .7476+03 |
| 26 | 8 | SYMM | .9663+03 |
| 27 | 6 | ASYM | .1175+04 |
| 28 | 6 | SYMM | .1250+04 |
| 29 | 7 | ASYM | .1270+04 |
| 30 | 7 | SYMM | .1344+04 |
| 31 | 8 | ASYM | .1394+04 |
| 32 | 9 | ASYM | .1476+04 |

CSR: BUCKLING EIGENVALUE PRINTOUT (cont.)

EIGENVALUES

SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

| HARMONICS: | | | | |
|------------|---------|---------|---------|---------|
| MODE | 6 | 7 | 8 | 9 |
| 1 | .193+03 | .127+03 | .109+03 | .110+03 |
| 2 | .208+03 | .182+03 | .158+03 | .138+03 |
| 3 | .476+03 | .477+03 | .494+03 | .538+03 |
| 4 | .125+04 | .134+04 | .966+03 | .748+03 |

EIGENVALUE CONVERGENCE MATRIX

SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

| HARMONICS: | | | | |
|------------|----------|----------|----------|----------|
| MODE | 6 | 7 | 8 | 9 |
| 1 | -.135-04 | -.334-05 | -.173-05 | -.333-05 |
| 2 | -.388-03 | -.183-03 | -.624-04 | -.422-04 |
| 3 | -.620-02 | -.990-02 | -.153-01 | -.631-01 |
| 4 | -.861-01 | -.253-01 | -.154-01 | -.541-01 |

EIGENVALUES

ANTI-SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

| HARMONICS: | | | | |
|------------|---------|---------|---------|---------|
| MODE | 6 | 7 | 8 | 9 |
| 1 | .193+03 | .127+03 | .109+03 | .110+03 |
| 2 | .208+03 | .182+03 | .158+03 | .138+03 |
| 3 | .476+03 | .477+03 | .495+03 | .544+03 |
| 4 | .118+04 | .127+04 | .139+04 | .148+04 |

EIGENVALUE CONVERGENCE MATRIX

ANTI-SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

| HARMONICS: | | | | |
|------------|----------|----------|----------|----------|
| MODE | 6 | 7 | 8 | 9 |
| 1 | -.679-05 | -.223-05 | -.360-05 | -.103-04 |
| 2 | -.323-03 | -.102-03 | -.319-04 | -.114-04 |
| 3 | -.465-02 | -.508-02 | -.108-01 | -.199-01 |
| 4 | -.511-01 | -.481-01 | -.564-01 | -.130+00 |

Each EIGENVALUE CONVERGENCE MATRIX is computed as $(E-P)/E$, where

E= matrix of eigenvalues, and

P= matrix of eigenvalues from the next-to-last EIG iteration.

4. EXAMPLES

Examples are presented in the following sections for static, buckling, and vibrational analyses of cyclically symmetrical structures with and without planes of reflective symmetry. The results computed with the cyclic symmetry models are compared with the results obtained with quarter or half models.

Generic model procedures were used to generate all finite element grids used in the following examples.

4.1 GENERIC MODELS USED TO COMPUTE EXAMPLE SOLUTIONS

The runstream elements MODEL BUILDER and RAIL WHEEL are used in the following examples to generate the required finite element grids. MODEL BUILDER is used for all cylindrical, conical, and spherical shell models. RAIL WHEEL is used for all rail wheel models.

In subsequent sections, the following symbols are used:

E= modulus of elasticity,
v= poisson's ratio,
 ρ = weight density,
 α = thermal expansion coefficient, and
t= shell thickness.

MODEL BUILDER and RAIL WHEEL are located in the EAL procedure library for example problems (EAL027 at most installations). With EAL027 attached as EAL Library 27, proceed as follows:

- o To obtain MODEL BUILDER

```
*XQT U1
*CALL(27 CS DEMO)
```

The above call causes MODEL BUILDER to be entered into LIB 29 along with runstream elements for each of the cylinder, cone, and sphere examples that follow in this section.

- o To obtain RAIL WHEEL

```
*XQT U1
*CALL(27 RAIL MODELS)
```

The above call causes RAIL WHEEL to be entered into LIB 29 along with runstream elements for each of the rail wheel examples that follow in this section.

4.1.1 CYLINDRICAL, CONICAL, AND SPHERICAL SHELL MODELS

The runstream element MODEL BUILDER generates cyclic symmetry finite element models for cylindrical, conical, and spherical shells. MODEL BUILDER may be used for models including or excluding reflective symmetry. A finite element model produced by MODEL BUILDER is made up of a strip, one element wide, of n quadrilateral elements lying along a shell generator. Data sets containing the following information are automatically produced by MODEL BUILDER:

- o Joint Locations
- o Joint Reference Frame Orientations (Cylindrical),
- o Material Constants,
- o Shell Section Properties,
- o E43 Element Definitions, and
- o Cyclic Symmetry Boundary Joint Definitions

For models with reflective symmetry, the global y axis is normal to the reflective plane.

To conform with the requirement that all joints lying on the central axis must be fully constrained, spherical models are produced by MODEL BUILDER with a small hole at the apex. This modeling technique introduced no appreciable error in the computed solutions.

To use MODEL BUILDER proceed as shown below, see Examples 4.3.1, 4.2.1, and 4.3.4 for definitions of the symbols used:

- o For a cylinder:

```
*XQT U1
*(CYLINDER DEFINITION)
  E    v    ρ    α    t    radius    height    θ    n
*Call (MODEL BUILDER)
```

- o For a cone:

```
*XQT U1
*(CONE DEFINITION)
  E    v    ρ    α    t    rad1    rad2    height    θ    n
*Call (MODEL BUILDER)
```

- o For a sphere:

```
*XQT U1
*(SPHERE DEFINITION)
  E    v    ρ    α    t    radius    θ    γ    n
*Call (MODEL BUILDER)
```


To use (MODEL BUILDER) proceed as follows:

- o For a cylinder:

```
*XQT U1
*(CYLINDER DEFINITION)
  E    v    ρ    α    t    radius    height    θ    n
*Call (MODEL BUILDER)
```

See Example 4.3.1 for definitions of the above items.

- o For a cone:

```
*XQT U1
*(CONE DEFINITION)
  E    v    ρ    α    t    rad1    rad2    height    θ    n
*Call (MODEL BUILDER)
```

See Example 4.2.1 for definitions of the above items.

- o For a sphere:

```
*XQT U1
*(SPHERE DEFINITION)
  E    v    ρ    α    t    radius    θ    γ    n
*Call (MODEL BUILDER)
```

See Example 4.3.4 for definitions of the above items.

4.1.2 RAIL WHEEL MODELS

The runstream element RAIL WHEEL generates finite element models for the rail wheel examples presented in subsequent sections (see Section 4.3.5). The number of circumferential subdivisions and the total central angle dimension of the desired rail wheel model is specified by the user. Consequently, RAIL WHEEL may be used to generate half models and quarter models in addition to cyclic symmetry models.

For cyclic symmetry + reflective symmetry models, the global y axis is normal to the reflective plane.

Data sets containing the following information are automatically produced by RAIL WHEEL:

- o Joint Locations,
- o Joint Reference Frame Orientations (Cylindrical),
- o Joint Elimination Sequence,
- o Material Constants
- o S81 Element Definitions.

Data sets containing the cyclic symmetry boundary joints must be specified by the user.

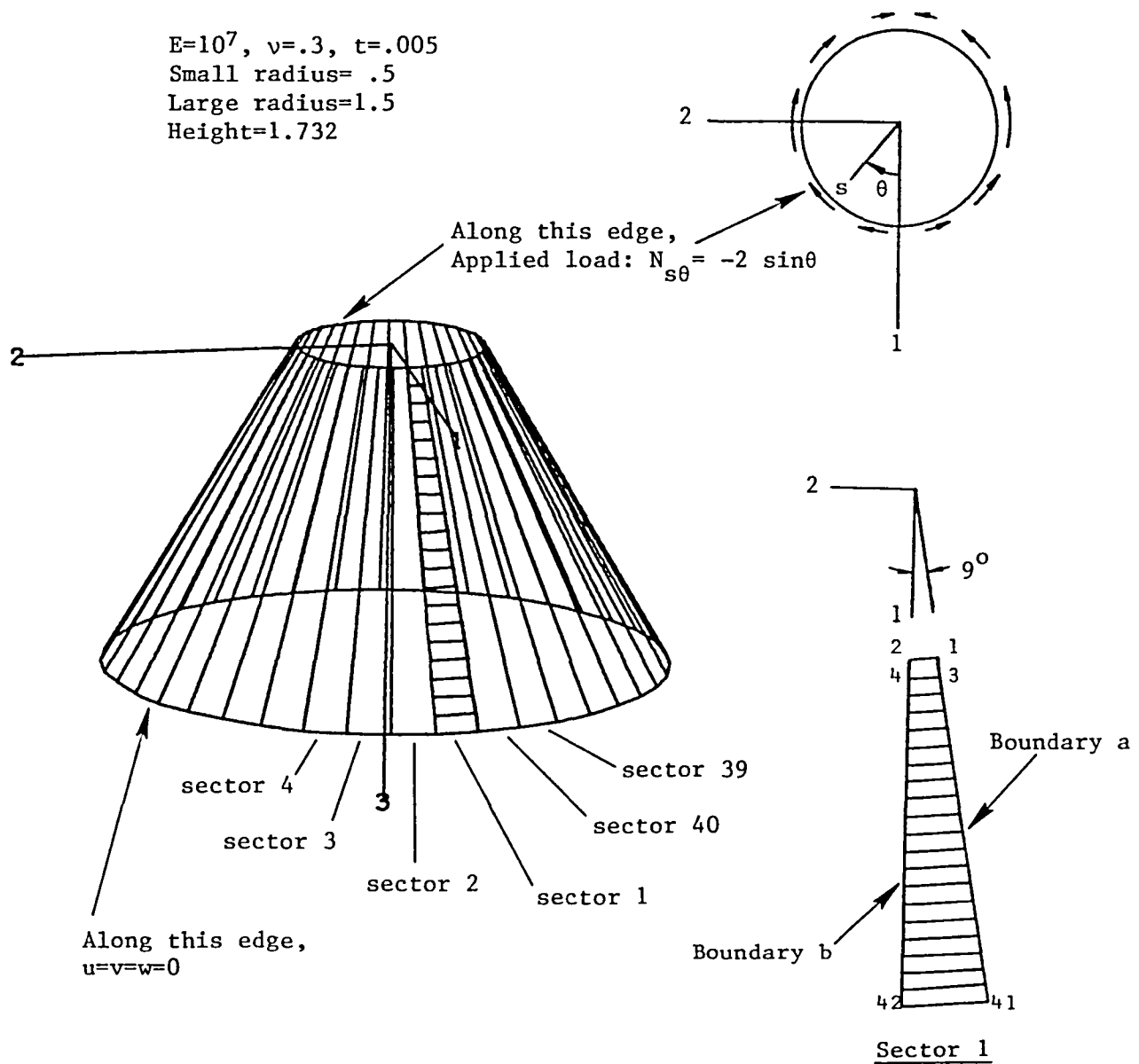
To use RAIL WHEEL proceed as follows:

```
*XQT U1
*(RAIL OPTIONS)
    !NTHETA = number of circumferential
                subdivisions
    ! THETA = total central angle dimension
                of the model in degrees
*(ISOTROPIC SOLIDS)
    J=1:  E    v    ρ    α    yn    ys
*CALL (RAIL WHEEL)
```

In the above, y_n and y_s are reference yield values for normal stress and yield stress. In the subsequent examples, $a=y_n=y_s=0$.

4.2.1 CS: CONICAL SHELL, EDGE LOADING

The runstream for the problem described below is shown on the next page. The computed results agree exactly with those obtained with the quarter model described in Volume 3 of the EAL Reference Manual. Sample stress printout from the cyclic symmetry solution is shown on page 4.2.1-2.



```

*XQT U1
*(CONE DEFINITION)
  10.+6 .3 .1 1.-5 .005 .5 1.5 1.732 9. 20
$ E NU RHO ALPHA T RAD1 RAD2 HEIGHT THETA ELEMENTS
*DCALL(MODEL BUILDER)
*XQT AUS
$
$ FORCE VECTOR COMPUTATION:
  OUTLIB=5: INLIB=5: SYSVEC: F1: I=2: J=1: .15707963
  TABLE(NJ=40): THETA: DDATA=9.: J=1,40: 0.
  SNT=SIN(.017453293 THETA): APPL FORC=CBR(F1,SNT)
  TABLE(NI=18,NJ=1,,TYPE=4): TITLE FORC: J=1
    'EDGE LOADING, CONICAL SHELL, CYCLIC SYMMETRY MODEL
  TABLE(NJ=40,TYPE=0): SECT FORC: DDATA=1: RJ=1,40: 1
$
$ SOLUTION CONTROL DATA SETS:
  TABLE(NJ=1,TYPE=0): HARMONICS: J=1: 1
  TABLE(NJ=4,TYPE=0): BACK SECTORS: J=1,4: 1: 4: 7: 10
*XQT U1
*(CONSTRAINTS)
  ZERO 1 2 3: 41,42
*(OPTIONS)
  !NSECTORS=40: !PROB='STAT
*(ES OPTIONS)
  NODES=0: DISPLAY=MSR
*CALL(CS)

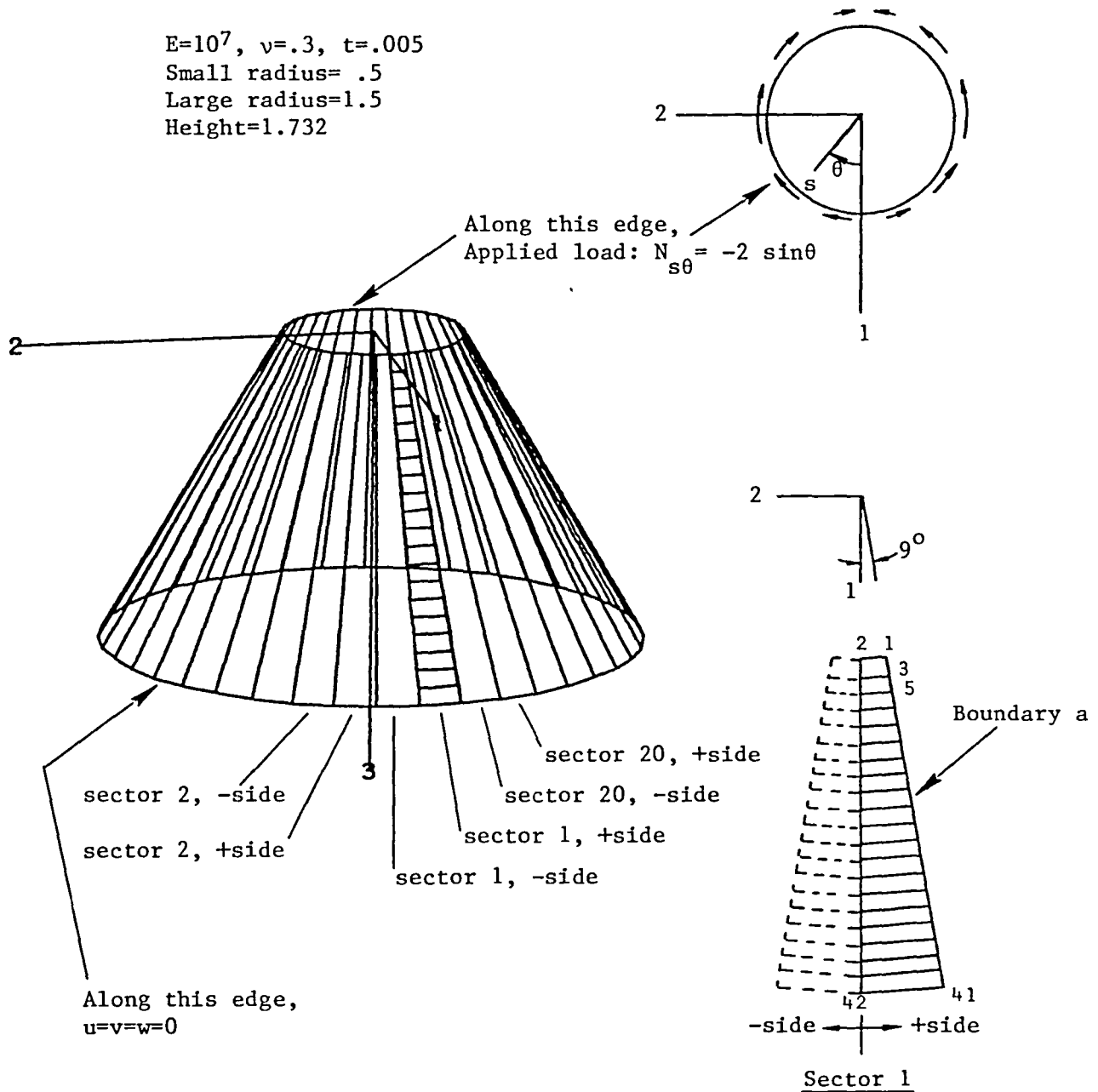
```

PAGE 1 CYCLIC SYMMETRY, ELEMENT STRESSES, SECTOR 1
 S/C 1/ 1 EDGE LOADING, CONICAL SHELL, CYCLIC SYMMETRY MODEL
 E43

| GRP-IND*/ | | NX | NY | NXY | ANG | MAX PN | MIN PN | MAX SHR |
|-----------|-----|----------|---------|----------|------|---------|----------|---------|
| JOINTS | | | | | | | | |
| 1- | 1* | .637-01 | .178+00 | -.143+00 | 124. | .274+00 | -.330-01 | .154+00 |
| 1- | 2* | -.179-01 | .452+00 | -.119+00 | 103. | .480+00 | -.463-01 | .263+00 |
| 1- | 3* | -.205-02 | .638+00 | -.101+00 | 99. | .653+00 | -.175-01 | .335+00 |
| 1- | 4* | -.147-02 | .767+00 | -.863-01 | 96. | .776+00 | -.110-01 | .394+00 |
| 1- | 5* | -.257-02 | .855+00 | -.748-01 | 95. | .861+00 | -.904-02 | .435+00 |
| 1- | 6* | -.207-02 | .915+00 | -.655-01 | 94. | .919+00 | -.672-02 | .463+00 |
| 1- | 7* | -.189-02 | .954+00 | -.578-01 | 93. | .957+00 | -.537-02 | .481+00 |
| 1- | 8* | -.176-02 | .978+00 | -.514-01 | 93. | .981+00 | -.445-02 | .493+00 |
| 1- | 9* | -.162-02 | .992+00 | -.460-01 | 93. | .994+00 | -.374-02 | .499+00 |
| 1- | 10* | -.149-02 | .998+00 | -.414-01 | 92. | .100+01 | -.320-02 | .502+00 |
| 1- | 11* | -.137-02 | .998+00 | -.374-01 | 92. | .100+01 | -.277-02 | .501+00 |
| 1- | 12* | -.125-02 | .994+00 | -.340-01 | 92. | .995+00 | -.241-02 | .499+00 |
| 1- | 13* | -.115-02 | .987+00 | -.311-01 | 92. | .987+00 | -.213-02 | .495+00 |
| 1- | 14* | -.123-02 | .977+00 | -.285-01 | 92. | .977+00 | -.206-02 | .490+00 |
| 1- | 15* | -.113-02 | .965+00 | -.262-01 | 92. | .966+00 | -.184-02 | .484+00 |
| 1- | 16* | .626-03 | .952+00 | -.242-01 | 91. | .953+00 | .108-04 | .476+00 |
| 1- | 17* | .445-04 | .939+00 | -.224-01 | 91. | .939+00 | -.490-03 | .470+00 |
| 1- | 18* | -.160-01 | .924+00 | -.208-01 | 91. | .925+00 | -.165-01 | .471+00 |
| 1- | 19* | -.121-01 | .909+00 | -.195-01 | 91. | .910+00 | -.125-Q1 | .461+00 |
| 1- | 20* | .138+00 | .896+00 | -.180-01 | 91. | .896+00 | .137+00 | .380+00 |

4.2.2 CSR: CONICAL SHELL, EDGE LOADING

The runstream for the problem described below is shown on the next page. The computed results agree exactly with those obtained with the quarter model described in Volume 3 of the EAL Reference Manual. Sample stress printout for the cyclic symmetry + reflective symmetry solution is shown on page 4.2.2-2.



```

*XQT U1
*(CONE DEFINITION)
  10.+6 .3 .1 1.-5 .005 .5 1.5 1.732 9. 20
$ E NU RHO ALPHA T RAD1 RAD2 HEIGHT THETA ELEMENTS
*DCALL(MODEL BUILDER)
*XQT AUS
$ APPLIED FORCE COMPUTATION:
  OUTLIB=5: INLIB=5: SYSVEC: F1: I=2: J=1,2: .15707963 .15514572
  SYSVEC: F2: I=2: J=2: -.02457267
  TABLE(NJ=20): THETA: DDATA=18.:J=1,20:0.: CST=cos(.017453293 THETA)
  SNT=sin(.017453293 THETA): F+ FORC=CBR(F1,SNT): F- FORC=CBR(F2,CST)
  TABLE(NI=18,NJ=1,,TYPE=4): TITLE FORC: J=1
    'EDGE LOADING, CONICAL SHELL, CYCLIC SYMMETRY MODEL
  TABLE(NJ=20,TYPE=0): SECT FORC: DDATA=1: RJ=1,20: 1
$ SOLUTION CONTROL DATA SETS:
  TABLE(NJ=1,TYPE=0): HARMONICS: J=1: 1
  TABLE(NJ=4,TYPE=0): BACK SECTORS: J=1,4: 1: 3: 4: 6
*XQT U1
*(CONSTRAINTS)
  ZERO 1 2 3: 41,42
*(OPTIONS)
  !NSECTORS=20: !RFLP=2: !PROB='STAT
*(ES OPTIONS)
  NODES=0: DISPLAY=MSR
*CALL(CSR)

```

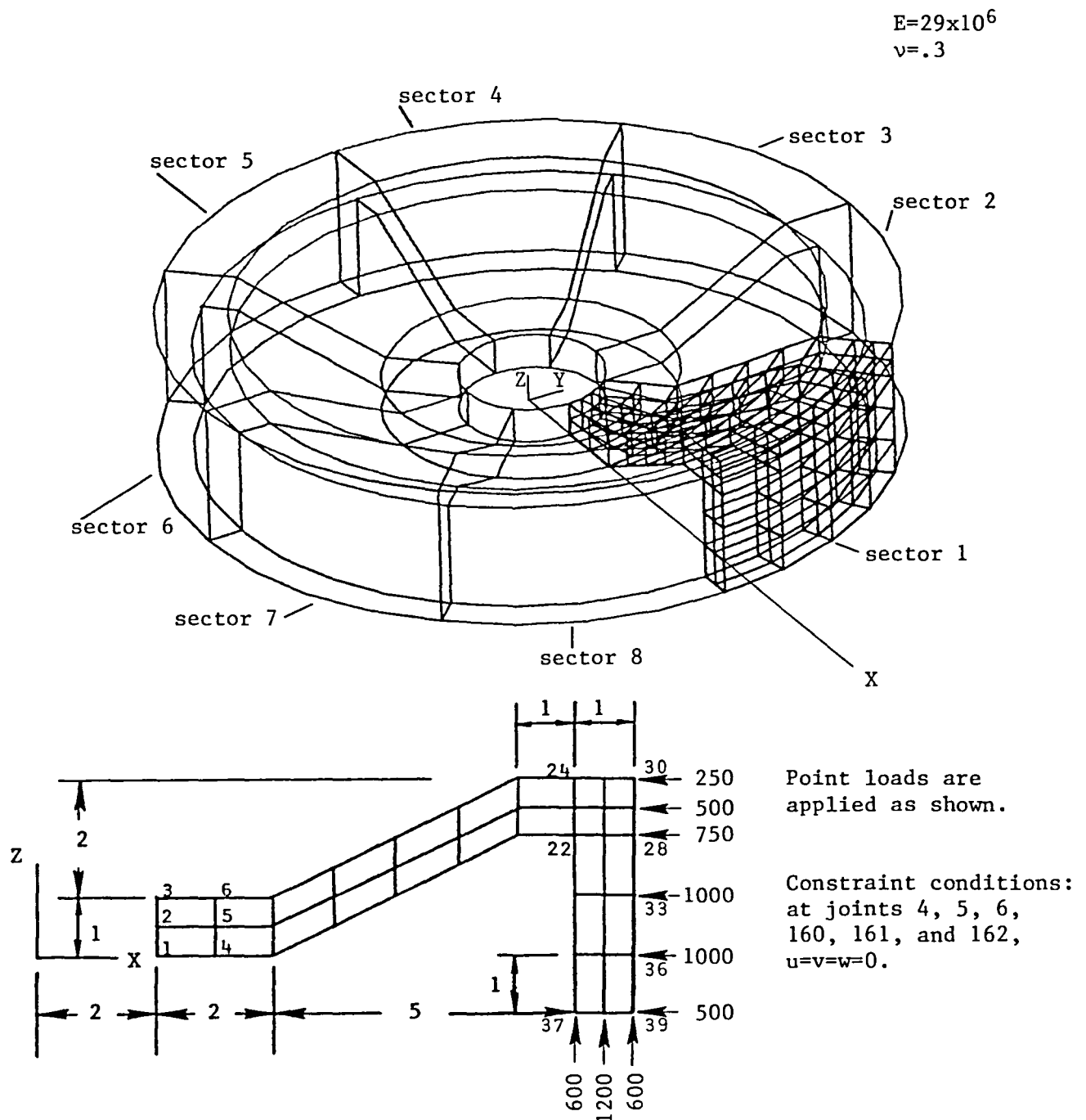
PAGE 1 CYCLIC SYMMETRY, +SIDE ELEMENT STRESSES, SECTOR 1
 S/C 1/ 1 EDGE LOADING, CONICAL SHELL, CYCLIC SYMMETRY MODEL
 E43

GRP-IND*/

| JOINTS | | NX | NY | NX Y | ANG | MAX PN | MIN PN | MAX SHR |
|--------|-----|----------|---------|----------|------|---------|----------|---------|
| 1- | 1* | .637-01 | .178+00 | -.143+00 | 124. | .274+00 | -.330-01 | .154+00 |
| 1- | 2* | -.179-01 | .452+00 | -.119+00 | 103. | .480+00 | -.463-01 | .263+00 |
| 1- | 3* | -.206-02 | .638+00 | -.101+00 | 99. | .653+00 | -.175-01 | .335+00 |
| 1- | 4* | -.147-02 | .767+00 | -.863-01 | 96. | .776+00 | -.110-01 | .394+00 |
| 1- | 5* | -.257-02 | .855+00 | -.748-01 | 95. | .861+00 | -.904-02 | .435+00 |
| 1- | 6* | -.207-02 | .915+00 | -.655-01 | 94. | .919+00 | -.672-02 | .463+00 |
| 1- | 7* | -.189-02 | .954+00 | -.578-01 | 93. | .957+00 | -.537-02 | .481+00 |
| 1- | 8* | -.176-02 | .978+00 | -.514-01 | 93. | .981+00 | -.445-02 | .493+00 |
| 1- | 9* | -.161-02 | .992+00 | -.460-01 | 93. | .994+00 | -.373-02 | .499+00 |
| 1- | 10* | -.148-02 | .998+00 | -.414-01 | 92. | .100+01 | -.319-02 | .502+00 |
| 1- | 11* | -.137-02 | .998+00 | -.374-01 | 92. | .100+01 | -.277-02 | .501+00 |
| 1- | 12* | -.125-02 | .994+00 | -.340-01 | 92. | .995+00 | -.241-02 | .499+00 |
| 1- | 13* | -.115-02 | .987+00 | -.311-01 | 92. | .987+00 | -.213-02 | .495+00 |
| 1- | 14* | -.124-02 | .977+00 | -.285-01 | 92. | .977+00 | -.207-02 | .490+00 |
| 1- | 15* | -.113-02 | .965+00 | -.262-01 | 92. | .966+00 | -.184-02 | .484+00 |
| 1- | 16* | .612-03 | .952+00 | -.242-01 | 91. | .953+00 | -.428-05 | .476+00 |
| 1- | 17* | .267-04 | .939+00 | -.224-01 | 91. | .939+00 | -.509-03 | .470+00 |
| 1- | 18* | -.160-01 | .924+00 | -.209-01 | 91. | .925+00 | -.164-01 | .471+00 |
| 1- | 19* | -.120-01 | .909+00 | -.194-01 | 91. | .910+00 | -.125-01 | .461+00 |
| 1- | 20* | .138+00 | .896+00 | -.181-01 | 91. | .896+00 | .137+00 | .380+00 |

4.2.3 CS: RAIL WHEEL, POINT LOADS

The runstream for the problem described below is shown on the next page. The computed results agree exactly with those obtained with a half model of the wheel. Sample stress printout from the cyclic symmetry solution is shown on page 4.2.3-3.



```

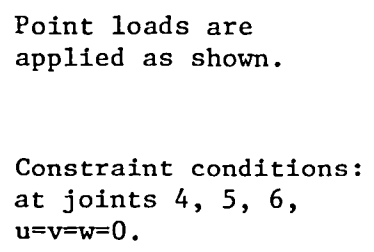
*XQT U1
*(RAIL OPTIONS)
!NTHETA=4: !THETA=45.
*(ISOTROPIC SOLIDS)$      E      NU      RHO      OTHERS
  J=1:                    29.+6   .3      .28      0. 0. 0.
*DCALL(RAIL WHEEL)
*XQT AUS
TABLE(NJ=39,TYPE=0): JA: DDATA=1: RJ=1,39: 1
TABLE(NJ=39,TYPE=0): JB: DDATA=1: RJ=1,39: 157
TABLE(NI=18,NJ=1,TYPE=4): 5 TITLE FORC: J=1
  'RAIL WHEEL, POINT LOADS APPLIED AT STATION 1
TABLE(NJ=1,TYPE=0): 5 SECT FORC: J=1: 1
SYSVEC: 5 APPL FORC
  I=1: J=   28:   29:   30:   33:   36:   39
          -750.: -500.: -250.: -1000.: -1000.: -500.
  I=3: J=   37:   38:   39
          600.: 1200.: 600.
*XQT U1
*(CONSTRAINTS)
  ZERO 1 2 3: 4,6: 160,162: "JTS"
*(OPTIONS)
  !NSECTORS=8: !PROB='STAT
*(ES OPTIONS)
  NODES=0: D3D=3
*CALL(CS)

```


PAGE 1 CYCLIC SYMMETRY, ELEMENT STRESSES, SECTOR 4
 S/C 1/ 4 RAIL WHEEL, POINT LOADS APPLIED AT STATION 1
 S81

| STRESSES | | | ONS | OSS | SI | SYR |
|----------|-------|--|----------|---------|---------|------|
| GRP-IND* | JOINT | | | | | |
| 1/ 1* | MID | | -.113+03 | .453+03 | .106+04 | .000 |
| 1/ 2* | MID | | .161+03 | .378+03 | .888+03 | .000 |
| 1/ 3* | MID | | -.786+03 | .573+03 | .137+04 | .000 |
| 1/ 4* | MID | | .674+03 | .855+03 | .196+04 | .000 |
| 1/ 5* | MID | | -.451+03 | .451+03 | .109+04 | .000 |
| 1/ 6* | MID | | -.282+02 | .389+03 | .952+03 | .000 |
| 1/ 7* | MID | | -.280+03 | .284+03 | .677+03 | .000 |
| 1/ 8* | MID | | -.205+02 | .292+03 | .714+03 | .000 |
| 1/ 9* | MID | | -.923+02 | .129+03 | .281+03 | .000 |
| 1/ 10* | MID | | -.209+02 | .198+03 | .480+03 | .000 |
| 1/ 11* | MID | | .137+02 | .514+02 | .125+03 | .000 |
| 1/ 12* | MID | | .750+01 | .122+03 | .300+03 | .000 |
| 1/ 13* | MID | | .923+02 | .423+02 | .103+03 | .000 |
| 1/ 14* | MID | | .138+02 | .110+03 | .268+03 | .000 |
| 1/ 15* | MID | | .579+02 | .564+02 | .137+03 | .000 |
| 1/ 16* | MID | | .203+02 | .106+03 | .259+03 | .000 |
| 1/ 17* | MID | | -.258+01 | .105+03 | .254+03 | .000 |
| 1/ 18* | MID | | .275+02 | .847+02 | .204+03 | .000 |
| 1/ 19* | MID | | -.423+02 | .769+02 | .176+03 | .000 |
| 1/ 20* | MID | | -.844+01 | .488+02 | .119+03 | .000 |
| 1/ 21* | MID | | -.430+02 | .981+02 | .227+03 | .000 |
| 1/ 22* | MID | | -.367+02 | .132+03 | .318+03 | .000 |
| 1/ 23* | MID | | .695+02 | .604+02 | .133+03 | .000 |
| 1/ 24* | MID | | -.325+02 | .129+03 | .310+03 | .000 |
| 1/ 25* | MID | | -.362+03 | .320+03 | .783+03 | .000 |
| 1/ 26* | MID | | .214+03 | .266+03 | .639+03 | .000 |
| 1/ 27* | MID | | -.456+03 | .377+03 | .920+03 | .000 |
| 1/ 28* | MID | | .156+03 | .380+03 | .890+03 | .000 |
| 1/ 29* | MID | | -.521+03 | .464+03 | .113+04 | .000 |
| 1/ 30* | MID | | .914+02 | .381+03 | .932+03 | .000 |
| 1/ 31* | MID | | -.320+03 | .290+03 | .711+03 | .000 |
| 1/ 32* | MID | | -.127+02 | .213+03 | .522+03 | .000 |
| 1/ 33* | MID | | -.876+02 | .106+03 | .236+03 | .000 |
| 1/ 34* | MID | | .600+00 | .175+03 | .426+03 | .000 |
| 1/ 35* | MID | | .539+02 | .590+02 | .144+03 | .000 |
| 1/ 36* | MID | | .302+02 | .185+03 | .451+03 | .000 |
| 1/ 37* | MID | | .164+03 | .722+02 | .164+03 | .000 |
| 1/ 38* | MID | | .337+02 | .181+03 | .442+03 | .000 |
| 1/ 39* | MID | | .963+02 | .693+02 | .169+03 | .000 |
| 1/ 40* | MID | | .390+02 | .160+03 | .392+03 | .000 |
| 1/ 41* | MID | | -.309+01 | .122+03 | .291+03 | .000 |
| 1/ 42* | MID | | .469+02 | .125+03 | .299+03 | .000 |
| 1/ 43* | MID | | -.842+02 | .133+03 | .298+03 | .000 |
| 1/ 44* | MID | | -.238+02 | .867+02 | .212+03 | .000 |
| 1/ 45* | MID | | -.735+02 | .117+03 | .254+03 | .000 |
| 1/ 46* | MID | | -.602+02 | .120+03 | .282+03 | .000 |
| 1/ 47* | MID | | .110+03 | .771+02 | .170+03 | .000 |
| 1/ 48* | MID | | -.522+02 | .121+03 | .278+03 | .000 |

—



```

*XQT U1
*(RAIL OPTIONS)
!NTHETA=2: !THETA=22.5
*(ISOTROPIC SOLIDS)$      E      NU      RHO      OTHERS
J=1:                      29.+6   .3      .28      0. 0. 0.
*DCALL(RAIL WHEEL)
*XQT AUS
TABLE(NJ=39,TYPE=0): JA: DDATA=1: RJ=1,39: 79
TABLE(NI=18,NJ=1,TYPE=4): 5 TITLE FORC: J=1
'RAIL WHEEL, POINT LOADS APPLIED AT STATION 1
TABLE(NJ=1,TYPE=0): 5 SECT FORC: J=1: 1
SYSVEC: 5 F+ FORC
      I=1: J=   28:   29:   30:   33:   36:   39
              -750.: -500.: -250.: -1000.: -1000.: -500.
      I=3: J=   37:   38:   39
              600.: 1200.: 600.
OUTLIB=5: INLIB=5: F- FORC= UNION(0. F+)
*XQT U1
*(CONSTRAINTS)
ZERO 1 2 3: 4,6: "JTS"
*(OPTIONS)
!NSECTORS=8: !PROB='STAT
*(ES OPTIONS)
NODES=0: D3D=3
*CALL(CSR)

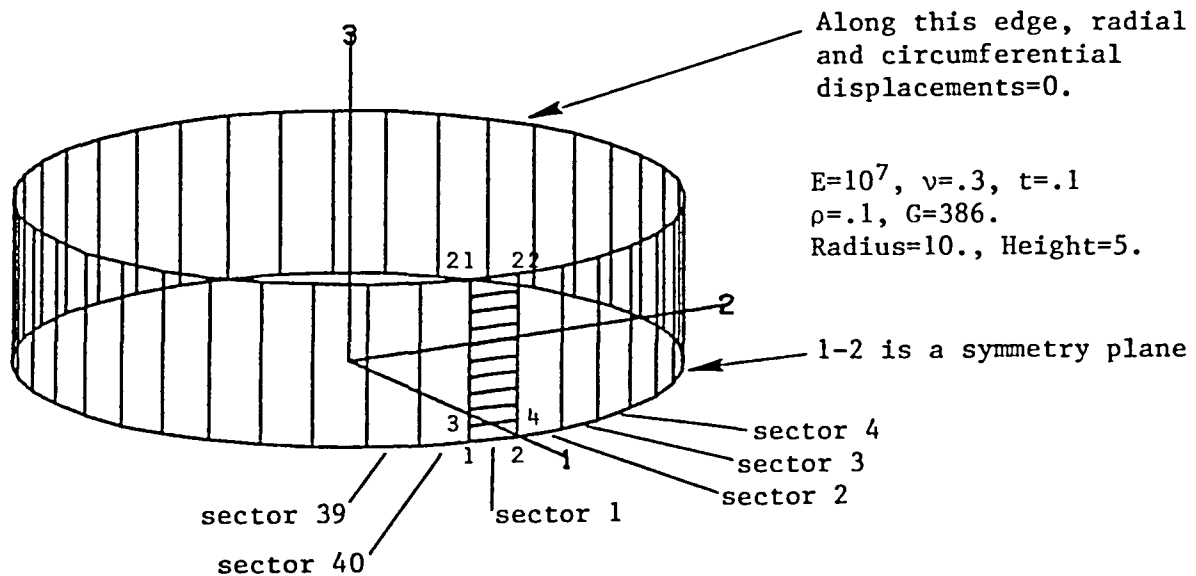
```

PAGE 1 CYCLIC SYMMETRY, +SIDE ELEMENT STRESSES, SECTOR 6
 S/C 1/ 6 RAIL WHEEL, POINT LOADS APPLIED AT STATION 1
 S81

| STRESSES | | | | | |
|----------|-------|----------|---------|---------|------|
| GRP-IND* | JOINT | ONS | OSS | SI | SYR |
| 1/ 1* | MID | -.113+03 | .453+03 | .106+04 | .000 |
| 1/ 2* | MID | .161+03 | .378+03 | .888+03 | .000 |
| 1/ 3* | MID | -.786+03 | .573+03 | .137+04 | .000 |
| 1/ 4* | MID | .674+03 | .855+03 | .196+04 | .000 |
| 1/ 5* | MID | -.451+03 | .451+03 | .109+04 | .000 |
| 1/ 6* | MID | -.282+02 | .388+03 | .952+03 | .000 |
| 1/ 7* | MID | -.280+03 | .284+03 | .677+03 | .000 |
| 1/ 8* | MID | -.205+02 | .292+03 | .714+03 | .000 |
| 1/ 9* | MID | -.923+02 | .129+03 | .281+03 | .000 |
| 1/ 10* | MID | -.209+02 | .198+03 | .480+03 | .000 |
| 1/ 11* | MID | .137+02 | .514+02 | .125+03 | .000 |
| 1/ 12* | MID | .750+01 | .122+03 | .300+03 | .000 |
| 1/ 13* | MID | .923+02 | .423+02 | .103+03 | .000 |
| 1/ 14* | MID | .138+02 | .110+03 | .268+03 | .000 |
| 1/ 15* | MID | .579+02 | .564+02 | .137+03 | .000 |
| 1/ 16* | MID | .203+02 | .106+03 | .259+03 | .000 |
| 1/ 17* | MID | -.258+01 | .105+03 | .254+03 | .000 |
| 1/ 18* | MID | .275+02 | .848+02 | .204+03 | .000 |
| 1/ 19* | MID | -.423+02 | .769+02 | .176+03 | .000 |
| 1/ 20* | MID | -.844+01 | .488+02 | .119+03 | .000 |
| 1/ 21* | MID | -.430+02 | .981+02 | .227+03 | .000 |
| 1/ 22* | MID | -.367+02 | .132+03 | .318+03 | .000 |
| 1/ 23* | MID | .695+02 | .604+02 | .133+03 | .000 |
| 1/ 24* | MID | -.325+02 | .129+03 | .310+03 | .000 |
| 1/ 25* | MID | -.362+03 | .320+03 | .783+03 | .000 |
| 1/ 26* | MID | .214+03 | .266+03 | .639+03 | .000 |
| 1/ 27* | MID | -.456+03 | .377+03 | .920+03 | .000 |
| 1/ 28* | MID | .156+03 | .380+03 | .890+03 | .000 |
| 1/ 29* | MID | -.521+03 | .464+03 | .113+04 | .000 |
| 1/ 30* | MID | .914+02 | .381+03 | .932+03 | .000 |
| 1/ 31* | MID | -.320+03 | .290+03 | .711+03 | .000 |
| 1/ 32* | MID | -.127+02 | .213+03 | .522+03 | .000 |
| 1/ 33* | MID | -.876+02 | .106+03 | .236+03 | .000 |
| 1/ 34* | MID | .599+00 | .175+03 | .426+03 | .000 |
| 1/ 35* | MID | .539+02 | .590+02 | .144+03 | .000 |
| 1/ 36* | MID | .302+02 | .185+03 | .451+03 | .000 |
| 1/ 37* | MID | .164+03 | .721+02 | .164+03 | .000 |
| 1/ 38* | MID | .337+02 | .181+03 | .442+03 | .000 |
| 1/ 39* | MID | .963+02 | .693+02 | .169+03 | .000 |
| 1/ 40* | MID | .390+02 | .160+03 | .392+03 | .000 |
| 1/ 41* | MID | -.309+01 | .122+03 | .291+03 | .000 |
| 1/ 42* | MID | .469+02 | .125+03 | .299+03 | .000 |
| 1/ 43* | MID | -.842+02 | .133+03 | .298+03 | .000 |
| 1/ 44* | MID | -.238+02 | .867+02 | .212+03 | .000 |
| 1/ 45* | MID | -.735+02 | .117+03 | .254+03 | .000 |
| 1/ 46* | MID | -.602+02 | .120+03 | .282+03 | .000 |
| 1/ 47* | MID | .110+03 | .771+02 | .170+03 | .000 |
| 1/ 48* | MID | -.522+02 | .121+03 | .278+03 | .000 |

4.3.1 CS: VIBRATIONAL MODES OF A CYLINDRICAL SHELL

The runstream for the problem described below is shown at the bottom of the page. The computed results agree exactly with those obtained with the quarter model described in Volume 3 of the EAL Reference Manual. Sample printout from the cyclic symmetry solution is shown on pages 4.3.1-2 and 4.3.1-3.



```
*XQT U1
*(CYLINDER DEFINITION)
    10.+6 .3 .1 1.-5 .1 10. 5. 9. 10
$   E  NU  RHO  ALPHA  T  RADIUS  HEIGHT  THETA  ELEMENTS
*DCALL(MODEL BUILDER)
*XQT AUS
    TABLE(NJ=8,TYPE=0): 5 HARMONICS: DDATA=1: RJ=1,8: 4
    TABLE(NJ=1,TYPE=0): 5 BACK SECTORS: J=1: 1
*XQT U1
*(CONSTRAINTS)
    SYMM PLANE=3: ZERO 1 2: 21,22
*(OPTIONS)
    !NSECTORS=40: !G=386.: !MNAME='CEM
    !INIT=6: !NREQ=4: !NVECTORS=4: !NEVALS=4
*CALL(CS)
```

CYCLIC SYMMETRY VIBRATIONAL EIGENVALUES FOLLOW:

| MODE | HARMONIC NUMBER | EIGENVALUE | HZ |
|------|--------------------|------------|---------|
| 1 | 7 | .2259+08 | 756.38 |
| 2 | 7 | .2259+08 | 756.38 |
| 3 | 6 | .2473+08 | 791.50 |
| 4 | 6 | .2473+08 | 791.50 |
| 5 | 8 | .2567+08 | 806.41 |
| 6 | 8 | .2567+08 | 806.41 |
| 7 | 9 | .3331+08 | 918.51 |
| 8 | 9 | .3331+08 | 918.51 |
| 9 | 5 | .3428+08 | 931.88 |
| 10 | 5 | .3428+08 | 931.88 |
| 11 | 10 | .4558+08 | 1074.50 |
| 12 | 10 | .4558+08 | 1074.50 |
| 13 | 4 | .5630+08 | 1194.21 |
| 14 | 4 | .5630+08 | 1194.21 |
| 15 | 11 | .6303+08 | 1263.55 |
| 16 | 11 | .6303+08 | 1263.55 |
| 17 | 9 | .2276+09 | 2401.31 |
| 18 | 9 | .2276+09 | 2401.31 |
| 19 | 10 | .2317+09 | 2422.47 |
| 20 | 10 | .2317+09 | 2422.47 |
| 21 | 8 | .2335+09 | 2431.80 |
| 22 | 8 | .2335+09 | 2431.80 |
| 23 | 11 | .2464+09 | 2498.18 |
| 24 | 11 | .2464+09 | 2498.18 |
| 25 | 7 | .2482+09 | 2507.14 |
| 26 | 7 | .2482+09 | 2507.14 |
| 27 | 6 | .2704+09 | 2616.91 |
| 28 | 6 | .2704+09 | 2616.91 |
| 29 | 5 | .2981+09 | 2747.97 |
| 30 | 5 | .2981+09 | 2747.97 |
| 31 | 4 | .3287+09 | 2885.61 |
| 32 | 4 | .3287+09 | 2885.62 |

VIBRATIONAL FREQUENCIES, HZ

| HARMONICS: | | | | | | | |
|------------|---------|---------|---------|---------|---------|---------|---------|
| MODE | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | .119+04 | .932+03 | .791+03 | .756+03 | .806+03 | .919+03 | .107+04 |
| 2 | .119+04 | .932+03 | .791+03 | .756+03 | .806+03 | .919+03 | .107+04 |
| 3 | .289+04 | .275+04 | .262+04 | .251+04 | .243+04 | .240+04 | .242+04 |
| 4 | .289+04 | .275+04 | .262+04 | .251+04 | .243+04 | .240+04 | .242+04 |

| HARMONICS: | |
|------------|---------|
| MODE | 11 |
| 1 | .126+04 |
| 2 | .126+04 |
| 3 | .250+04 |
| 4 | .250+04 |

EIGENVALUES

| HARMONICS: | | | | | | | |
|------------|---------|---------|---------|---------|---------|---------|---------|
| MODE | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | .563+08 | .343+08 | .247+08 | .226+08 | .257+08 | .333+08 | .456+08 |
| 2 | .563+08 | .343+08 | .247+08 | .226+08 | .257+08 | .333+08 | .456+08 |
| 3 | .329+09 | .298+09 | .270+09 | .248+09 | .233+09 | .228+09 | .232+09 |
| 4 | .329+09 | .298+09 | .270+09 | .248+09 | .233+09 | .228+09 | .232+09 |

| HARMONICS: | |
|------------|---------|
| MODE | 11 |
| 1 | .630+08 |
| 2 | .630+08 |
| 3 | .246+09 |
| 4 | .246+09 |

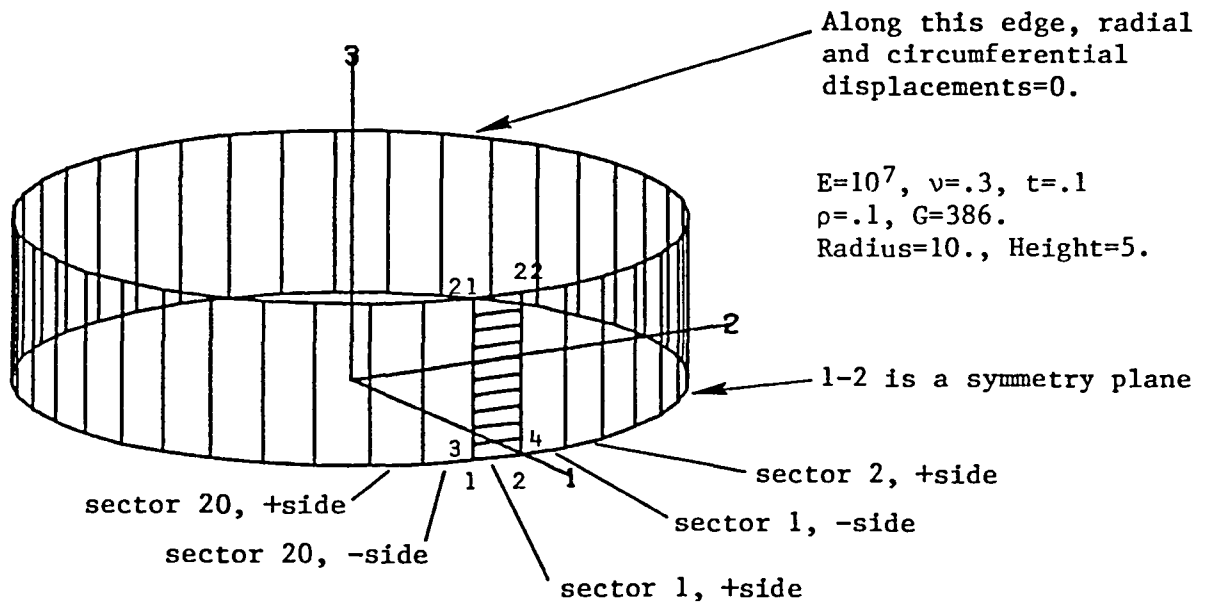
EIGENVALUE CONVERGENCE MATRIX

| HARMONICS: | | | | | | | |
|------------|----------|----------|----------|----------|----------|----------|----------|
| MODE | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| 2 | -.888-08 | .000 | .000 | .000 | .000 | .000 | .000 |
| 3 | -.243-07 | -.134-07 | .000 | -.806-08 | -.257-07 | -.351-07 | -.345-07 |
| 4 | -.845-04 | -.414-04 | -.192-04 | -.908-05 | -.479-05 | -.304-05 | -.253-05 |

| HARMONICS: | |
|------------|----------|
| MODE | 11 |
| 1 | .000 |
| 2 | .000 |
| 3 | -.114-06 |
| 4 | -.263-05 |

4.3.2 CSR: VIBRATIONAL MODES OF A CYLINDRICAL SHELL

The runstream for the problem described below is shown at the bottom of the page. The computed results agree exactly with those obtained with the quarter model described in Volume 3 of the EAL Reference Manual. Sample printout from the cyclic symmetry + reflective symmetry solution is shown on pages 4.3.2-2 through 4.3.2-4.



```
*XQT U1
*(CYLINDER DEFINITION)
  10.+6 .3 .1 1.-5 .1 10. 5. 9. 10
$   E  NU  RHO  ALPHA  T  RADIUS  HEIGHT  THETA  ELEMENTS
*DCALL(MODEL BUILDER)
*XQT AUS
  TABLE(NJ=8,TYPE=0): 5 HARMONICS: DDATA=1: RJ=1,8: 3
  TABLE(NJ=1,TYPE=0): 5 BACK SECTORS: J=1: 1
*XQT U1
*(CONSTRAINTS)
  SYMM PLANE=3: ZERO 1 2: 21,22
*(OPTIONS)
  !NSECTORS=20: !RFLP=2: !G=386.: !MNAME='CEM
  !NDYN=12: !INIT=4: !NREQ=4: !NVECTORS=2: !NEVALS=2
*CALL(CSR)
```


CYCLIC SYMMETRY VIBRATIONAL EIGENVALUES FOLLOW:

| MODE | HARMONIC NUMBER | REFLECTIVE BND. COND. | EIGENVALUE | HZ |
|------|--------------------|--------------------------|------------|---------|
| 1 | 7 | ASYM | .2259+08 | 756.37 |
| 2 | 7 | SYMM | .2259+08 | 756.37 |
| 3 | 6 | SYMM | .2473+08 | 791.48 |
| 4 | 6 | ASYM | .2473+08 | 791.48 |
| 5 | 8 | SYMM | .2567+08 | 806.41 |
| 6 | 8 | ASYM | .2567+08 | 806.41 |
| 7 | 9 | ASYM | .3331+08 | 918.51 |
| 8 | 9 | SYMM | .3331+08 | 918.52 |
| 9 | 5 | SYMM | .3428+08 | 931.86 |
| 10 | 5 | ASYM | .3428+08 | 931.86 |
| 11 | 10 | SYMM | .4558+08 | 1074.46 |
| 12 | 10 | ASYM | .4559+08 | 1074.58 |
| 13 | 4 | ASYM | .5630+08 | 1194.18 |
| 14 | 4 | SYMM | .5630+08 | 1194.18 |
| 15 | 9 | ASYM | .6303+08 | 1263.58 |
| 16 | 9 | SYMM | .6303+08 | 1263.58 |
| 17 | 8 | SYMM | .8648+08 | 1480.04 |
| 18 | 8 | ASYM | .8648+08 | 1480.04 |
| 19 | 3 | ASYM | .1009+09 | 1598.50 |
| 20 | 3 | SYMM | .1009+09 | 1598.50 |
| 21 | 7 | SYMM | .1169+09 | 1721.11 |
| 22 | 7 | ASYM | .1169+09 | 1721.11 |
| 23 | 6 | SYMM | .1556+09 | 1985.35 |
| 24 | 6 | ASYM | .1556+09 | 1985.35 |
| 25 | 5 | SYMM | .2038+09 | 2271.97 |
| 26 | 5 | ASYM | .2038+09 | 2271.98 |
| 27 | 10 | ASYM | .2316+09 | 2422.19 |
| 28 | 10 | SYMM | .2317+09 | 2422.76 |
| 29 | 4 | SYMM | .2629+09 | 2580.48 |
| 30 | 4 | ASYM | .2629+09 | 2580.49 |
| 31 | 3 | ASYM | .3344+09 | 2910.23 |
| 32 | 3 | SYMM | .3344+09 | 2910.23 |

VIBRATIONAL FREQUENCIES, HZ
 SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

| HARMONICS: | | | | | | | |
|------------|---------|---------|---------|---------|---------|---------|---------|
| MODE | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 1 | .160+04 | .119+04 | .932+03 | .791+03 | .756+03 | .806+03 | .919+03 |
| 2 | .291+04 | .258+04 | .227+04 | .199+04 | .172+04 | .148+04 | .126+04 |

| HARMONICS: | |
|------------|---------|
| MODE | 10 |
| 1 | .107+04 |
| 2 | .242+04 |

VIBRATIONAL FREQUENCIES, HZ
 ANTI-SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

| HARMONICS: | | | | | | | |
|------------|---------|---------|---------|---------|---------|---------|---------|
| MODE | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 1 | .160+04 | .119+04 | .932+03 | .791+03 | .756+03 | .806+03 | .919+03 |
| 2 | .291+04 | .258+04 | .227+04 | .199+04 | .172+04 | .148+04 | .126+04 |

| HARMONICS: | |
|------------|---------|
| MODE | 10 |
| 1 | .107+04 |
| 2 | .242+04 |

EIGENVALUES
 SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

| HARMONICS: | | | | | | | |
|------------|---------|---------|---------|---------|---------|---------|---------|
| MODE | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 1 | .101+09 | .563+08 | .343+08 | .247+08 | .226+08 | .257+08 | .333+08 |
| 2 | .334+09 | .263+09 | .204+09 | .156+09 | .117+09 | .865+08 | .630+08 |

| HARMONICS: | |
|------------|---------|
| MODE | 10 |
| 1 | .456+08 |
| 2 | .232+09 |

EIGENVALUE CONVERGENCE MATRIX
 SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

| HARMONICS: | | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|------------|----------|----------|----------|----------|------|----------|------|------|
| MODE | | | | | | | | |
| 1 | .000 | -.888-08 | .000 | .000 | .000 | .000 | .000 | .000 |
| 2 | -.120-07 | -.115-05 | -.785-07 | -.129-07 | .000 | -.116-07 | .000 | |

| HARMONICS: | | 10 |
|------------|------|----|
| MODE | | |
| 1 | .000 | |
| 2 | .000 | |

EIGENVALUES
 ANTI-SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

| HARMONICS: | | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|------------|---------|---------|---------|---------|---------|---------|---------|---|
| MODE | | | | | | | | |
| 1 | .101+09 | .563+08 | .343+08 | .247+08 | .226+08 | .257+08 | .333+08 | |
| 2 | .334+09 | .263+09 | .204+09 | .156+09 | .117+09 | .865+08 | .630+08 | |

| HARMONICS: | | 10 |
|------------|---------|----|
| MODE | | |
| 1 | .456+08 | |
| 2 | .232+09 | |

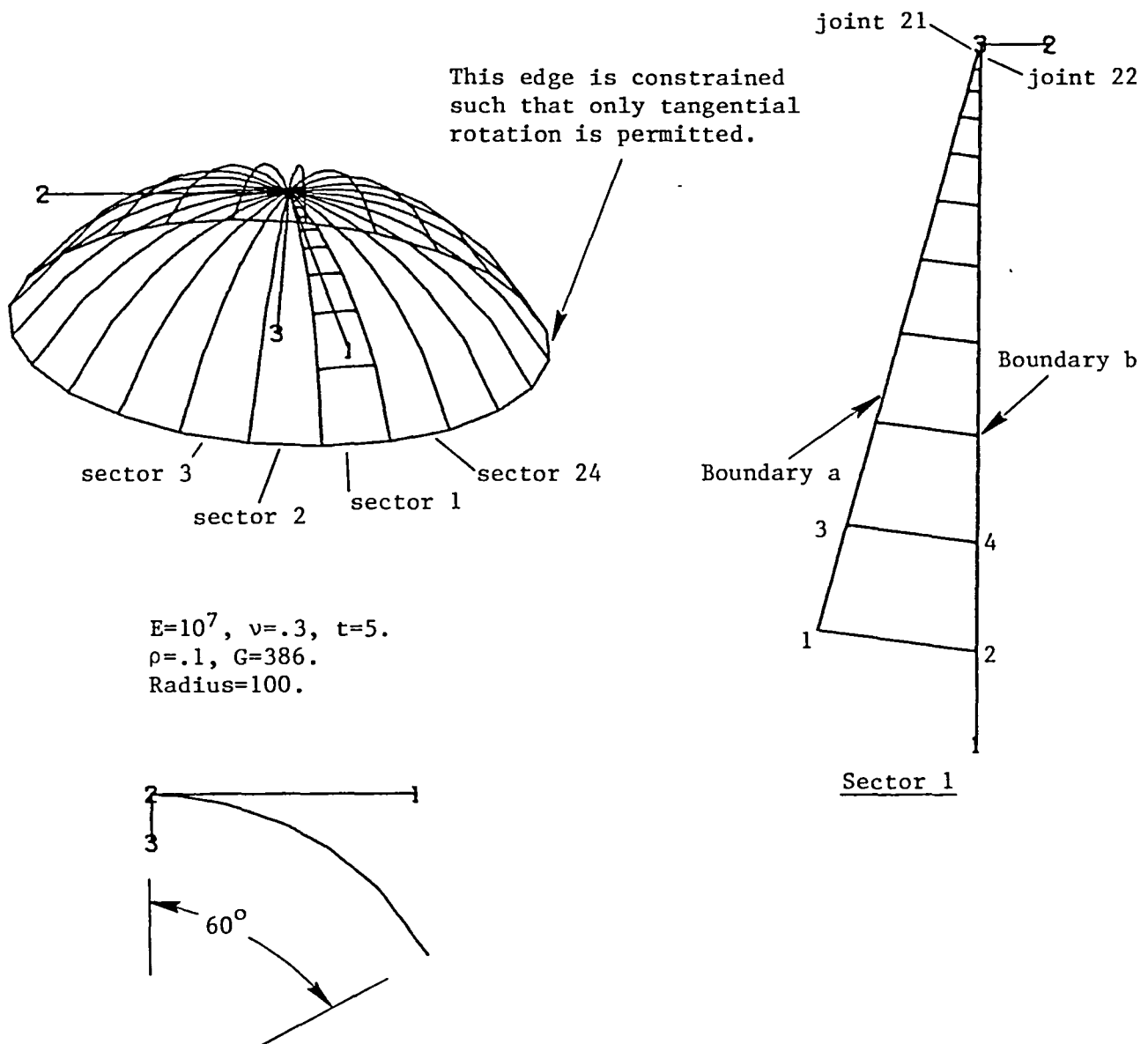
EIGENVALUE CONVERGENCE MATRIX
 ANTI-SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

| HARMONICS: | | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|------------|----------|----------|------|------|------|------|------|------|
| MODE | | | | | | | | |
| 1 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 |
| 2 | -.239-07 | -.152-07 | .000 | .000 | .000 | .000 | .000 | .000 |

| HARMONICS: | | 10 |
|------------|------|----|
| MODE | | |
| 1 | .000 | |
| 2 | .000 | |

4.3.3 CS: VIBRATIONAL MODES OF A 60 DEGREE SECTOR OF A SPHERICAL SHELL

The runstream for the problem described below is shown on the next page. For the zeroth harmonic, the lowest two computed frequencies were 298 Hz and 414 Hz. The corresponding frequencies obtained with the quarter model described in Volume 3 of the EAL Reference Manual were 300 Hz and 412 Hz. The solution discrepancies are attributable to differences between the two finite element grids. Sample printout from the cyclic symmetry solution is shown on pages 4.3.3-2 and 4.3.3-3.



```

*XQT U1
*(SPHERE DEFINITION)
  1.E+7  .3  .1  .1E-4  5.  100.  15.  60.  10
$  E    NU  RHO  ALPHA  T  RADIUS  THETA  GAMMA  ELEMENTS
*DCALL(MODEL BUILDER)
*XQT AUS
  TABLE(NJ=4,TYPE=0): 5 HARMONICS: DDATA=1: RJ=1,4: 0
  TABLE(NJ=1,TYPE=0): 5 BACK SECTORS: J=1: 1
*XQT U1
*(CONSTRAINTS)
  ZERO 1 2 3 4 6: 1,2
*(OPTIONS)
  !NSECTORS=24: !G=386.: !MNAME='CEM
  !INIT=6: !NREQ=4: !NVECTORS=4: !NEVALS=4: !ERCK=0
*CALL(CS)

```

CYCLIC SYMMETRY VIBRATIONAL EIGENVALUES FOLLOW:

| MODE | HARMONIC NUMBER | EIGENVALUE | HZ |
|------|--------------------|------------|--------|
| 1 | 1 | .2969+07 | 274.22 |
| 2 | 1 | .2969+07 | 274.22 |
| 3 | 0 | .3494+07 | 297.52 |
| 4 | 2 | .4335+07 | 331.39 |
| 5 | 2 | .4335+07 | 331.39 |
| 6 | 1 | .4785+07 | 348.13 |
| 7 | 1 | .4785+07 | 348.13 |
| 8 | 3 | .5248+07 | 364.61 |
| 9 | 3 | .5248+07 | 364.61 |
| 10 | 0 | .6754+07 | 413.62 |
| 11 | 2 | .6988+07 | 420.73 |
| 12 | 2 | .6988+07 | 420.73 |
| 13 | 0 | .9455+07 | 489.37 |
| 14 | 3 | .1051+08 | 515.87 |
| 15 | 3 | .1051+08 | 515.87 |
| 16 | 0 | .1685+08 | 653.35 |

VIBRATIONAL FREQUENCIES, HZ

| MODE | HARMONICS: | | | |
|------|------------|---------|---------|---------|
| | 0 | 1 | 2 | 3 |
| 1 | .298+03 | .274+03 | .331+03 | .365+03 |
| 2 | .414+03 | .274+03 | .331+03 | .365+03 |
| 3 | .489+03 | .348+03 | .421+03 | .516+03 |
| 4 | .653+03 | .348+03 | .421+03 | .516+03 |

EIGENVALUES

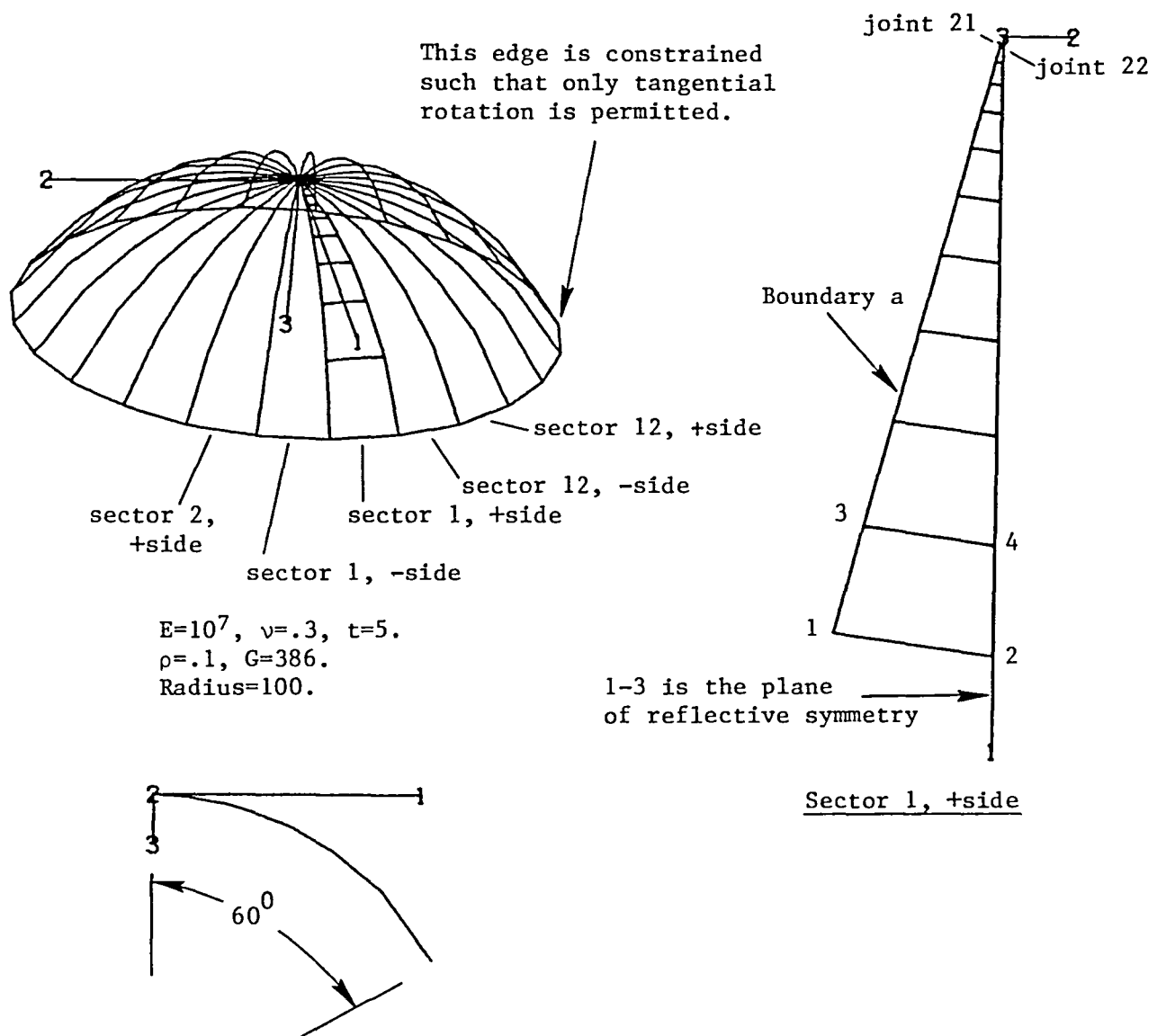
| MODE | HARMONICS: | | | |
|------|------------|---------|---------|---------|
| | 0 | 1 | 2 | 3 |
| 1 | .349+07 | .297+07 | .434+07 | .525+07 |
| 2 | .675+07 | .297+07 | .434+07 | .525+07 |
| 3 | .945+07 | .478+07 | .699+07 | .105+08 |
| 4 | .169+08 | .478+07 | .699+07 | .105+08 |

EIGENVALUE CONVERGENCE MATRIX

| MODE | HARMONICS: | | | |
|------|------------|----------|----------|----------|
| | 0 | 1 | 2 | 3 |
| 1 | .000 | -.211-07 | -.144-07 | -.119-07 |
| 2 | -.833-07 | -.105-07 | -.721-07 | -.167-06 |
| 3 | .000 | -.101-04 | -.485-04 | .000 |
| 4 | -.278-04 | -.350-04 | -.686-04 | -.234-04 |

4.3.4 CSR: VIBRATIONAL MODES OF A 60 DEGREE SECTOR OF A SPHERICAL SHELL

The runstream for the problem described below is shown on the next page. For the zeroth harmonic, the lowest two computed frequencies were 298 Hz and 414 Hz. The corresponding frequencies obtained with the quarter model described in Volume 3 of the EAL Reference Manual were 300 Hz and 412 Hz. The solution discrepancies are attributable to the differences between the two finite element grids. Sample printout from the cyclic symmetry + reflective symmetry solution is shown on pages 4.3.4-2 and 4.3.4-3.



```

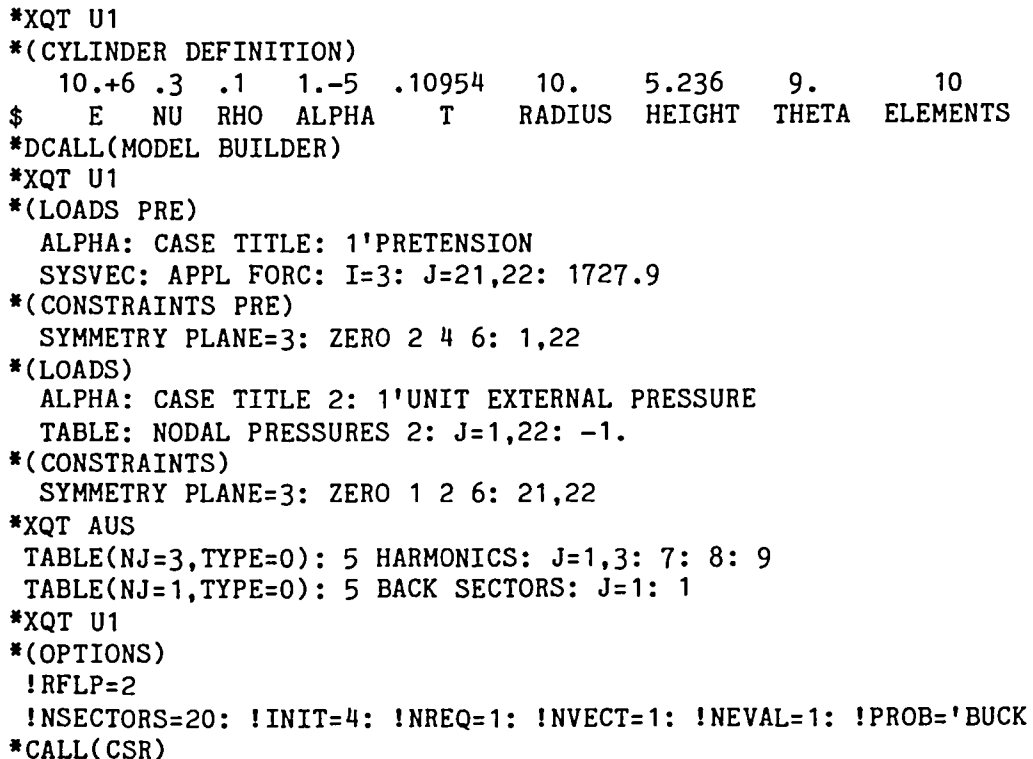
*XQT U1
*(SPHERE DEFINITION)
  1.E+7 .3 .1 .1E-4 5. 100. 15. 60. 10
$ E NU RHO ALPHA T RADIUS THETA GAMMA ELEMENTS
*DCALL(MODEL BUILDER)
*XQT AUS
  TABLE(NJ=4,TYPE=0): 5 HARMONICS: DDATA=1: RJ=1,4: 0
  TABLE(NJ=1,TYPE=0): 5 BACK SECTORS: J=1: 1
*XQT U1
*(CONSTRAINTS)
  ZERO 1 2 3 4 6: 1,2
*(OPTIONS)
  !NSECTORS=12: !RFLP=2: !G=386.: !MNAME='CEM
  !INIT=4: !NREQ=2: !NVECTORS=2: !NEVALS=2: !ERCK=0
*CALL(CSR)

```

CYCLIC SYMMETRY VIBRATIONAL EIGENVALUES FOLLOW:

| MODE | HARMONIC NUMBER | REFLECTIVE BND. COND. | EIGENVALUE | HZ |
|------|--------------------|--------------------------|------------|---------|
| 1 | 1 | ASYM | .2969+07 | 274.25 |
| 2 | 1 | SYMM | .2969+07 | 274.25 |
| 3 | 0 | SYMM | .3505+07 | 297.96 |
| 4 | 2 | ASYM | .4329+07 | 331.14 |
| 5 | 2 | SYMM | .4329+07 | 331.14 |
| 6 | 1 | SYMM | .4789+07 | 348.28 |
| 7 | 1 | ASYM | .4789+07 | 348.28 |
| 8 | 3 | ASYM | .5234+07 | 364.10 |
| 9 | 3 | SYMM | .5234+07 | 364.10 |
| 10 | 0 | SYMM | .6780+07 | 414.42 |
| 11 | 2 | SYMM | .6984+07 | 420.59 |
| 12 | 2 | ASYM | .6984+07 | 420.59 |
| 13 | 3 | ASYM | .1049+08 | 515.44 |
| 14 | 3 | SYMM | .1049+08 | 515.44 |
| 15 | 0 | ASYM | .1725+08 | 661.07 |
| 16 | 0 | ASYM | .7012+08 | 1332.73 |

The runstream for the problem described below is shown at the bottom of the page. The computed buckling pressure of 162.3 agrees exactly with the solution obtained with the quarter model described in Volume 3 of the EAL Reference Manual. Sample printout from the cyclic symmetry + reflective symmetry solution is shown on page 4.4.6-2.



VIBRATIONAL FREQUENCIES, HZ
 SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE
 HARMONICS:

| MODE | 0 | 1 | 2 | 3 |
|------|---------|---------|---------|---------|
| 1 | .298+03 | .274+03 | .331+03 | .364+03 |
| 2 | .414+03 | .348+03 | .421+03 | .515+03 |

VIBRATIONAL FREQUENCIES, HZ
 ANTI-SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE
 HARMONICS:

| MODE | 0 | 1 | 2 | 3 |
|------|---------|---------|---------|---------|
| 1 | .661+03 | .274+03 | .331+03 | .364+03 |
| 2 | .133+04 | .348+03 | .421+03 | .515+03 |

EIGENVALUES
 SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE
 HARMONICS:

| MODE | 0 | 1 | 2 | 3 |
|------|---------|---------|---------|---------|
| 1 | .351+07 | .297+07 | .433+07 | .523+07 |
| 2 | .678+07 | .479+07 | .698+07 | .105+08 |

EIGENVALUE CONVERGENCE MATRIX
 SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE
 HARMONICS:

| MODE | 0 | 1 | 2 | 3 |
|------|----------|----------|----------|----------|
| 1 | -.892-08 | .000 | .000 | .000 |
| 2 | -.251-04 | -.312-04 | -.233-04 | -.445-04 |

EIGENVALUES
 ANTI-SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE
 HARMONICS:

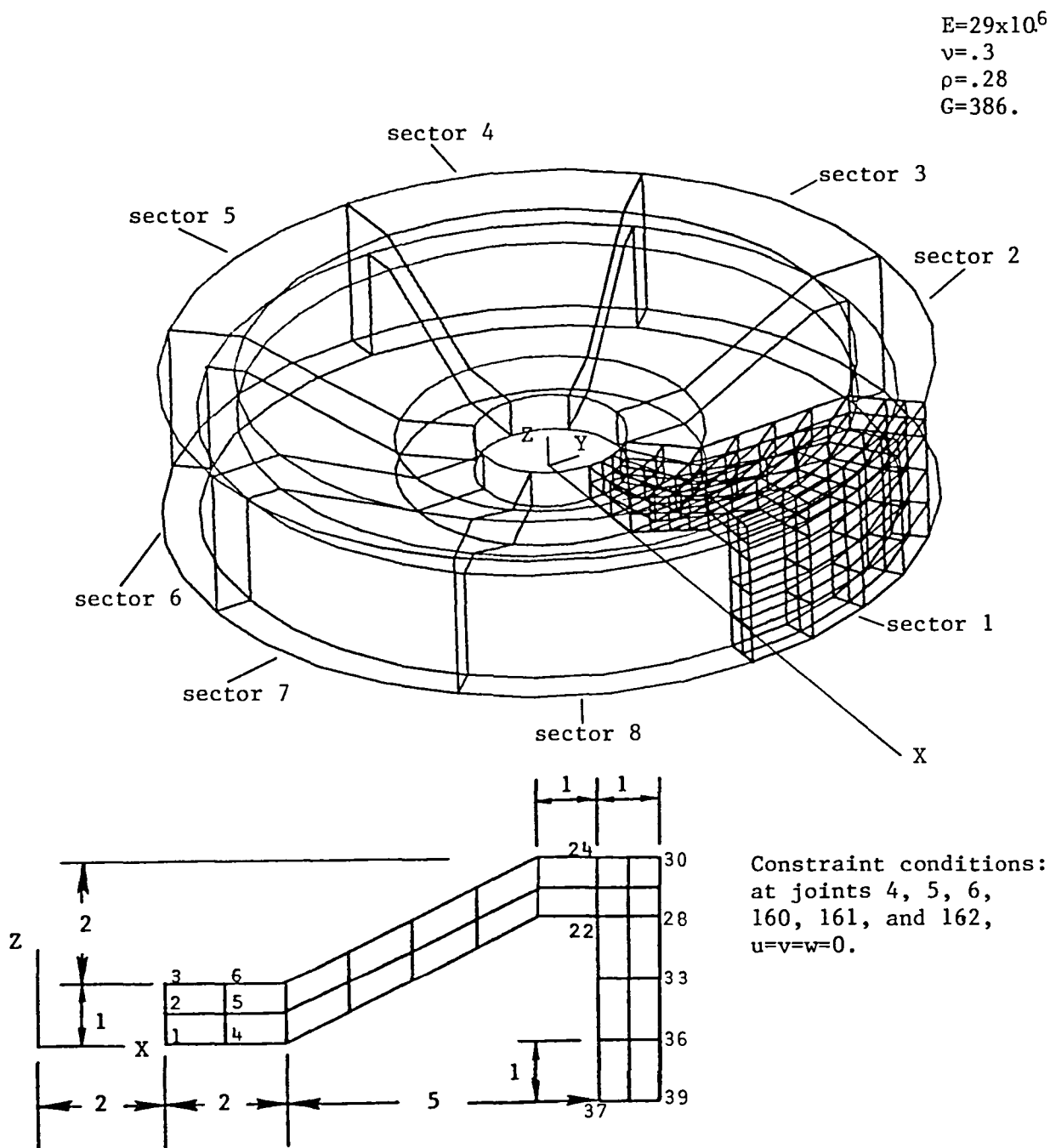
| MODE | 0 | 1 | 2 | 3 |
|------|---------|---------|---------|---------|
| 1 | .173+08 | .297+07 | .433+07 | .523+07 |
| 2 | .701+08 | .479+07 | .698+07 | .105+08 |

EIGENVALUE CONVERGENCE MATRIX
 ANTI-SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE
 HARMONICS:

| MODE | 0 | 1 | 2 | 3 |
|------|----------|----------|----------|----------|
| 1 | .000 | -.358-05 | -.228-05 | .000 |
| 2 | -.414-04 | -.193-04 | -.383-04 | -.375-05 |

4.3.5 CS: VIBRATIONAL MODES OF A RAIL WHEEL

The runstream for the problem described below is shown on the next page. The computed results agree exactly with those obtained with a half model of the wheel. Sample printout from the cyclic symmetry solution is shown on pages 4.3.5-2 and 4.3.5-3.



```

*XQT U1
*(RAIL OPTIONS)
!NTHETA=4: !THETA=45.
*(ISOTROPIC SOLIDS)$      E      NU      RHO      OTHERS
J=1:                      29.+6   .3      .28      0. 0. 0.
*DCALL(RAIL WHEEL)
*XQT AUS
TABLE(NJ=39,TYPE=0): JA: DDATA=1: RJ=1,39: 1
TABLE(NJ=39,TYPE=0): JB: DDATA=1: RJ=1,39: 157
*XQT U1
*(CONSTRAINTS)
ZERO 1 2 3: 4,6: 160,162: "JTS"
*(OPTIONS)
!NSECTORS=8: !G=386.
!INIT=10: !NREQ=8: !NVECTORS=6: !NEVALS=6: !NDYN=20: !VPRT=0
*CALL(CS)

```

CYCLIC SYMMETRY VIBRATIONAL EIGENVALUES FOLLOW:

| MODE | HARMONIC NUMBER | EIGENVALUE | HZ |
|------|--------------------|------------|---------|
| 1 | 1 | .7525+07 | 436.58 |
| 2 | 1 | .7525+07 | 436.58 |
| 3 | 2 | .2303+08 | 763.70 |
| 4 | 2 | .2303+08 | 763.70 |
| 5 | 0 | .2385+08 | 777.25 |
| 6 | 0 | .4940+08 | 1118.58 |
| 7 | 3 | .1109+09 | 1676.15 |
| 8 | 3 | .1109+09 | 1676.15 |
| 9 | 1 | .1158+09 | 1712.61 |
| 10 | 1 | .1158+09 | 1712.61 |
| 11 | 2 | .1803+09 | 2136.98 |
| 12 | 2 | .1803+09 | 2136.98 |
| 13 | 4 | .2615+09 | 2573.52 |
| 14 | 4 | .2615+09 | 2573.62 |
| 15 | 0 | .3246+09 | 2867.29 |
| 16 | 3 | .3725+09 | 3071.65 |
| 17 | 3 | .3725+09 | 3071.66 |
| 18 | 1 | .4745+09 | 3466.87 |
| 19 | 1 | .4745+09 | 3466.87 |
| 20 | 3 | .4950+09 | 3541.03 |
| 21 | 3 | .4950+09 | 3541.04 |
| 22 | 0 | .6263+09 | 3982.87 |
| 23 | 4 | .8097+09 | 4528.86 |
| 24 | 4 | .8128+09 | 4537.57 |
| 25 | 2 | .8424+09 | 4619.35 |
| 26 | 2 | .8424+09 | 4619.37 |
| 27 | 0 | .1424+10 | 6005.42 |
| 28 | 4 | .1754+10 | 6664.88 |
| 29 | 4 | .1776+10 | 6707.20 |
| 30 | 0 | .2110+10 | 7311.22 |

VIBRATIONAL FREQUENCIES, HZ

| MODE | HARMONICS: | | | | |
|------|------------|---------|---------|---------|---------|
| | 0 | 1 | 2 | 3 | 4 |
| 1 | .777+03 | .437+03 | .764+03 | .168+04 | .257+04 |
| 2 | .112+04 | .437+03 | .764+03 | .168+04 | .257+04 |
| 3 | .287+04 | .171+04 | .214+04 | .307+04 | .453+04 |
| 4 | .398+04 | .171+04 | .214+04 | .307+04 | .454+04 |
| 5 | .601+04 | .347+04 | .462+04 | .354+04 | .666+04 |
| 6 | .731+04 | .347+04 | .462+04 | .354+04 | .671+04 |

EIGENVALUES

| MODE | HARMONICS: | | | | |
|------|------------|---------|---------|---------|---------|
| | 0 | 1 | 2 | 3 | 4 |
| 1 | .238+08 | .752+07 | .230+08 | .111+09 | .261+09 |
| 2 | .494+08 | .752+07 | .230+08 | .111+09 | .261+09 |
| 3 | .325+09 | .116+09 | .180+09 | .372+09 | .810+09 |
| 4 | .626+09 | .116+09 | .180+09 | .372+09 | .813+09 |
| 5 | .142+10 | .474+09 | .842+09 | .495+09 | .175+10 |
| 6 | .211+10 | .474+09 | .842+09 | .495+09 | .178+10 |

EIGENVALUE CONVERGENCE MATRIX

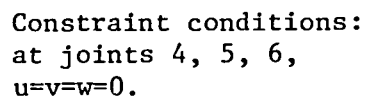
| MODE | HARMONICS: | | | | |
|------|------------|----------|----------|----------|----------|
| | 0 | 1 | 2 | 3 | 4 |
| 1 | .000 | .000 | .000 | .000 | .000 |
| 2 | .000 | .000 | .000 | .000 | .000 |
| 3 | .000 | .000 | -.111-07 | .000 | -.198-07 |
| 4 | .000 | .000 | .000 | -.215-07 | -.197-07 |
| 5 | -.450-07 | -.843-08 | -.824-05 | -.808-08 | -.173-05 |
| 6 | -.690-06 | .000 | -.137-04 | -.921-06 | -.270-06 |

The runstream for the problem described below is shown on the next page. The computed results agree exactly with those obtained with a half model of the wheel. Sample printout from the cyclic symmetry solution is shown on pages 4.3.6-2 and 4.3.6-3.

$$v=.3$$

$\rho = .28$

G=386.



```

*XQT U1
*(RAIL OPTIONS)
  !NTHETA=2: !THETA=22.5
*(ISOTROPIC SOLIDS)$      E      NU      RHO      OTHERS
  J=1:                    29.+6   .3      .28      0. 0. 0.
*DCALL(RAIL WHEEL)
*XQT AUS
  TABLE(NJ=39,TYPE=0): JA: DDATA=1: RJ=1,39: 79
*XQT U1
*(CONSTRAINTS)
  ZERO 1 2 3: 4,6: "JTS"
*(OPTIONS)
  !NSECTORS=8: !G=386.: !RFLP=2
  !INIT=6: !NREQ=4: !NVECTORS=3: !NEVALS=3: !NDYN=20: !VPRT=0
*CALL(CSR)

```

CYCLIC SYMMETRY VIBRATIONAL EIGENVALUES FOLLOW:

| MODE | HARMONIC NUMBER | REFLECTIVE BND. COND. | EIGENVALUE | HZ |
|------|--------------------|--------------------------|------------|---------|
| 1 | 1 | ASYM | .7525+07 | 436.58 |
| 2 | 1 | SYMM | .7525+07 | 436.58 |
| 3 | 2 | SYMM | .2303+08 | 763.70 |
| 4 | 2 | ASYM | .2303+08 | 763.71 |
| 5 | 0 | SYMM | .2385+08 | 777.25 |
| 6 | 0 | ASYM | .4940+08 | 1118.59 |
| 7 | 3 | ASYM | .1109+09 | 1676.15 |
| 8 | 3 | SYMM | .1109+09 | 1676.15 |
| 9 | 1 | SYMM | .1158+09 | 1712.61 |
| 10 | 1 | ASYM | .1158+09 | 1712.61 |
| 11 | 2 | SYMM | .1803+09 | 2136.98 |
| 12 | 2 | ASYM | .1803+09 | 2136.98 |
| 13 | 4 | ASYM | .2615+09 | 2573.52 |
| 14 | 4 | SYMM | .2615+09 | 2573.61 |
| 15 | 0 | SYMM | .3246+09 | 2867.29 |
| 16 | 3 | ASYM | .3725+09 | 3071.65 |
| 17 | 3 | SYMM | .3725+09 | 3071.65 |
| 18 | 1 | ASYM | .4745+09 | 3466.87 |
| 19 | 1 | SYMM | .4745+09 | 3466.87 |
| 20 | 3 | ASYM | .4950+09 | 3541.03 |
| 21 | 3 | SYMM | .4950+09 | 3541.03 |
| 22 | 0 | SYMM | .6263+09 | 3982.87 |
| 23 | 4 | ASYM | .8097+09 | 4528.86 |
| 24 | 4 | SYMM | .8128+09 | 4537.57 |
| 25 | 2 | SYMM | .8424+09 | 4619.35 |
| 26 | 2 | ASYM | .8424+09 | 4619.36 |
| 27 | 4 | ASYM | .1754+10 | 6664.88 |
| 28 | 4 | SYMM | .1776+10 | 6707.20 |
| 29 | 0 | ASYM | .2110+10 | 7311.21 |
| 30 | 0 | ASYM | .3578+10 | 9520.07 |

VIBRATIONAL FREQUENCIES, HZ
 SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

HARMONICS:

| MODE | 0 | 1 | 2 | 3 | 4 |
|------|---------|---------|---------|---------|---------|
| 1 | .777+03 | .437+03 | .764+03 | .168+04 | .257+04 |
| 2 | .287+04 | .171+04 | .214+04 | .307+04 | .454+04 |
| 3 | .398+04 | .347+04 | .462+04 | .354+04 | .671+04 |

VIBRATIONAL FREQUENCIES, HZ
 ANTI-SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

HARMONICS:

| MODE | 0 | 1 | 2 | 3 | 4 |
|------|---------|---------|---------|---------|---------|
| 1 | .112+04 | .437+03 | .764+03 | .168+04 | .257+04 |
| 2 | .731+04 | .171+04 | .214+04 | .307+04 | .453+04 |
| 3 | .952+04 | .347+04 | .462+04 | .354+04 | .666+04 |

EIGENVALUES
 SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

HARMONICS:

| MODE | 0 | 1 | 2 | 3 | 4 |
|------|---------|---------|---------|---------|---------|
| 1 | .238+08 | .752+07 | .230+08 | .111+09 | .261+09 |
| 2 | .325+09 | .116+09 | .180+09 | .372+09 | .813+09 |
| 3 | .626+09 | .474+09 | .842+09 | .495+09 | .178+10 |

EIGENVALUE CONVERGENCE MATRIX
 SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

HARMONICS:

| MODE | 0 | 1 | 2 | 3 | 4 |
|------|------|------|----------|----------|----------|
| 1 | .000 | .000 | .000 | .000 | .000 |
| 2 | .000 | .000 | -.111-07 | .000 | -.984-08 |
| 3 | .000 | .000 | -.463-04 | -.808-08 | -.991-07 |

EIGENVALUES
 ANTI-SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

HARMONICS:

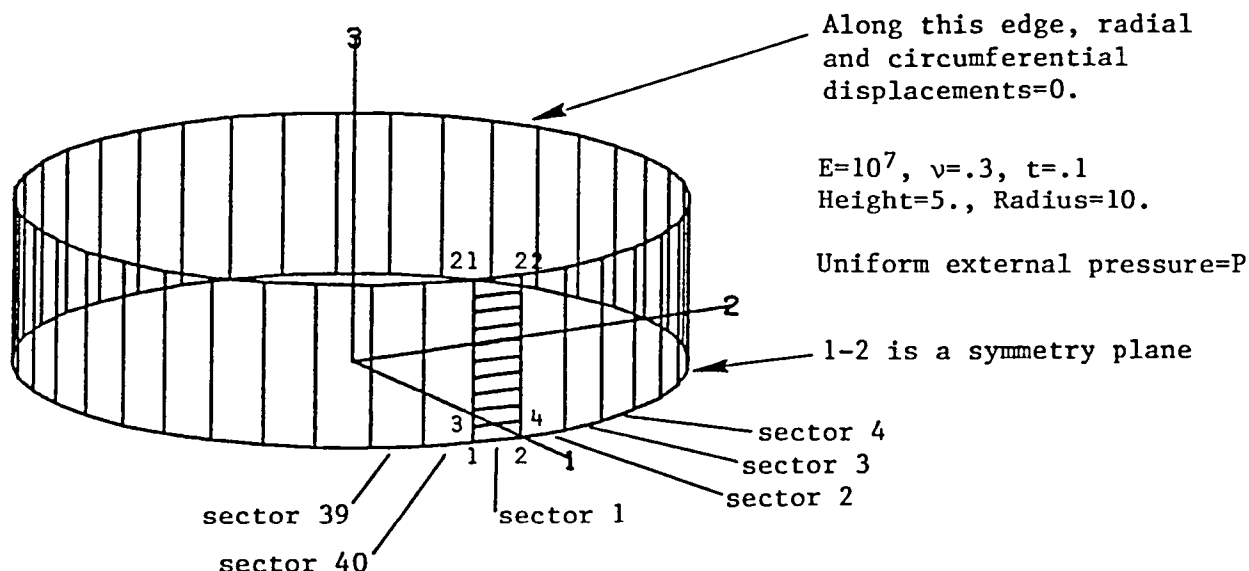
| MODE | 0 | 1 | 2 | 3 | 4 |
|------|---------|---------|---------|---------|---------|
| 1 | .494+08 | .752+07 | .230+08 | .111+09 | .261+09 |
| 2 | .211+10 | .116+09 | .180+09 | .372+09 | .810+09 |
| 3 | .358+10 | .474+09 | .842+09 | .495+09 | .175+10 |

EIGENVALUE CONVERGENCE MATRIX
 ANTI-SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

HARMONICS:

| MODE | 0 | 1 | 2 | 3 | 4 |
|------|----------|------|----------|----------|----------|
| 1 | .000 | .000 | .000 | .000 | .000 |
| 2 | -.607-07 | .000 | .000 | .000 | -.988-08 |
| 3 | -.349-06 | .000 | -.684-04 | -.242-07 | -.391-04 |

The runstream for the problem described below is shown at the bottom of the page. The computed buckling loads agree exactly with those obtained with the quarter model described in Volume 3 of the EAL Reference Manual. Sample printout from the cyclic symmetry solution is shown on page 4.4.1-2.



```

*QXT U1
*(CYLINDER DEFINITION)
      10.+6 .3 .1 1.-5 .1 10. 5. 9. 10
$      E NU RHO ALPHA T RADIUS HEIGHT THETA ELEMENTS
*DCALL(MODEL BUILDER)
*XQT U1
*(CONSTRAINTS PRE)
      SYMMETRY PLANE=3: ZERO 2 4 6: 1,22
*(CONSTRAINTS)
      SYMMETRY PLANE=3: ZERO 1 2: 21,22
*(LOADS)
      ALPHA: CASE TITLE: 1'UNIT EXTERNAL PRESSURE
      TABLE: NODAL PRESSURES: J=1,22: -1.
*XQT AUS
      TABLE(NJ=4,TYPE=0): 5 HARMONICS: J=1,4: 6: 7: 8: 9
      TABLE(NJ=1,TYPE=0): 5 BACK SECTORS: J=1: 1
*XQT U1
*(OPTIONS)
      !NSECTORS=40: !INIT=4: !NREQ=2: !NVECT=2: !NEVAL=2: !PROB='BUCK
*CALL(CS)

```

CYCLIC SYMMETRY BUCKLING EIGENVALUES FOLLOW:

| HARMONIC | | |
|----------|--------|------------|
| MODE | NUMBER | EIGENVALUE |
| 1 | 8 | .1089+03 |
| 2 | 8 | .1089+03 |
| 3 | 9 | .1105+03 |
| 4 | 9 | .1105+03 |
| 5 | 7 | .1270+03 |
| 6 | 7 | .1270+03 |
| 7 | 6 | .1934+03 |
| 8 | 6 | .1934+03 |

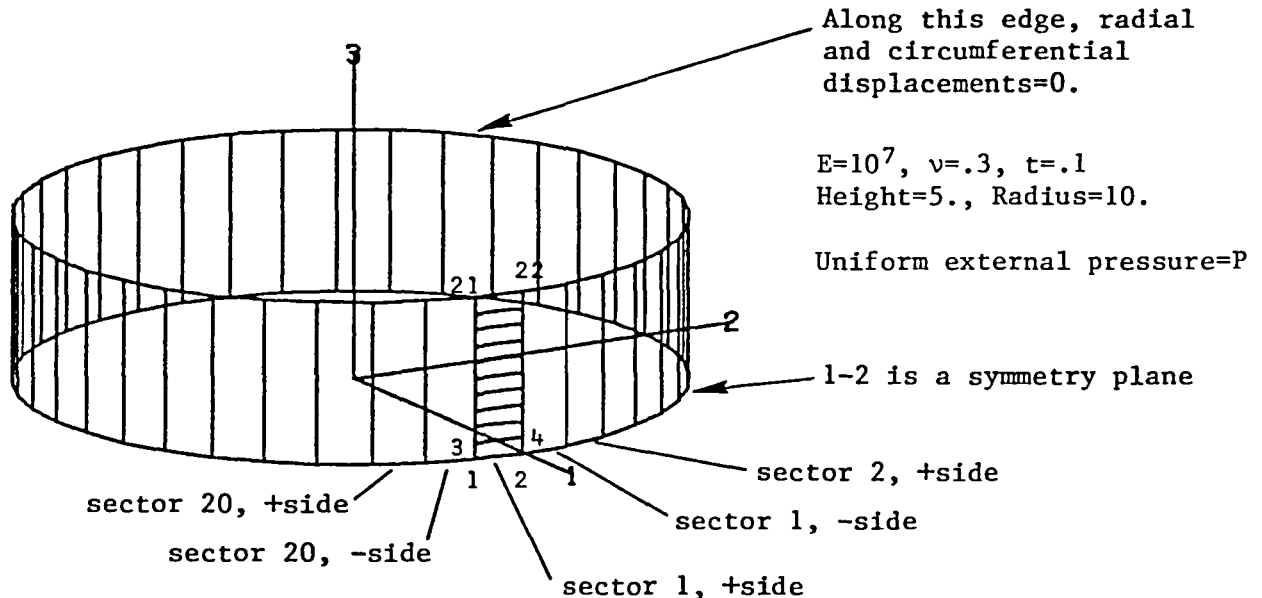
EIGENVALUES

| HARMONICS: | | | | |
|------------|---------|---------|---------|---------|
| MODE | 6 | 7 | 8 | 9 |
| 1 | .193+03 | .127+03 | .109+03 | .110+03 |
| 2 | .193+03 | .127+03 | .109+03 | .110+03 |

EIGENVALUE CONVERGENCE MATRIX

| HARMONICS: | | | | |
|------------|----------|----------|----------|----------|
| MODE | 6 | 7 | 8 | 9 |
| 1 | -.393-05 | -.871-06 | -.709-06 | -.107-05 |
| 2 | -.438-05 | -.931-06 | -.692-06 | -.122-05 |

4.4.2 CSR: BUCKLING OF A CYLINDRICAL SHELL DUE TO PRESSURE LOADING



CYCLIC SYMMETRY BUCKLING EIGENVALUES FOLLOW:

| MODE | HARMONIC NUMBER | REFLECTIVE BND. COND. | EIGENVALUE |
|------|--------------------|--------------------------|------------|
| 1 | 8 | SYMM | .1089+03 |
| 2 | 8 | ASYM | .1089+03 |
| 3 | 9 | ASYM | .1105+03 |
| 4 | 9 | SYMM | .1105+03 |
| 5 | 7 | ASYM | .1270+03 |
| 6 | 7 | SYMM | .1270+03 |
| 7 | 6 | SYMM | .1934+03 |
| 8 | 6 | ASYM | .1934+03 |

EIGENVALUES

SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

HARMONICS:

| MODE | 6 | 7 | 8 | 9 |
|------|---------|---------|---------|---------|
| 1 | .193+03 | .127+03 | .109+03 | .110+03 |

EIGENVALUE CONVERGENCE MATRIX

SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

HARMONICS:

| MODE | 6 | 7 | 8 | 9 |
|------|----------|----------|----------|----------|
| 1 | -.135-04 | -.325-05 | -.175-05 | -.328-05 |

EIGENVALUES

ANTI-SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

HARMONICS:

| MODE | 6 | 7 | 8 | 9 |
|------|---------|---------|---------|---------|
| 1 | .193+03 | .127+03 | .109+03 | .110+03 |

EIGENVALUE CONVERGENCE MATRIX

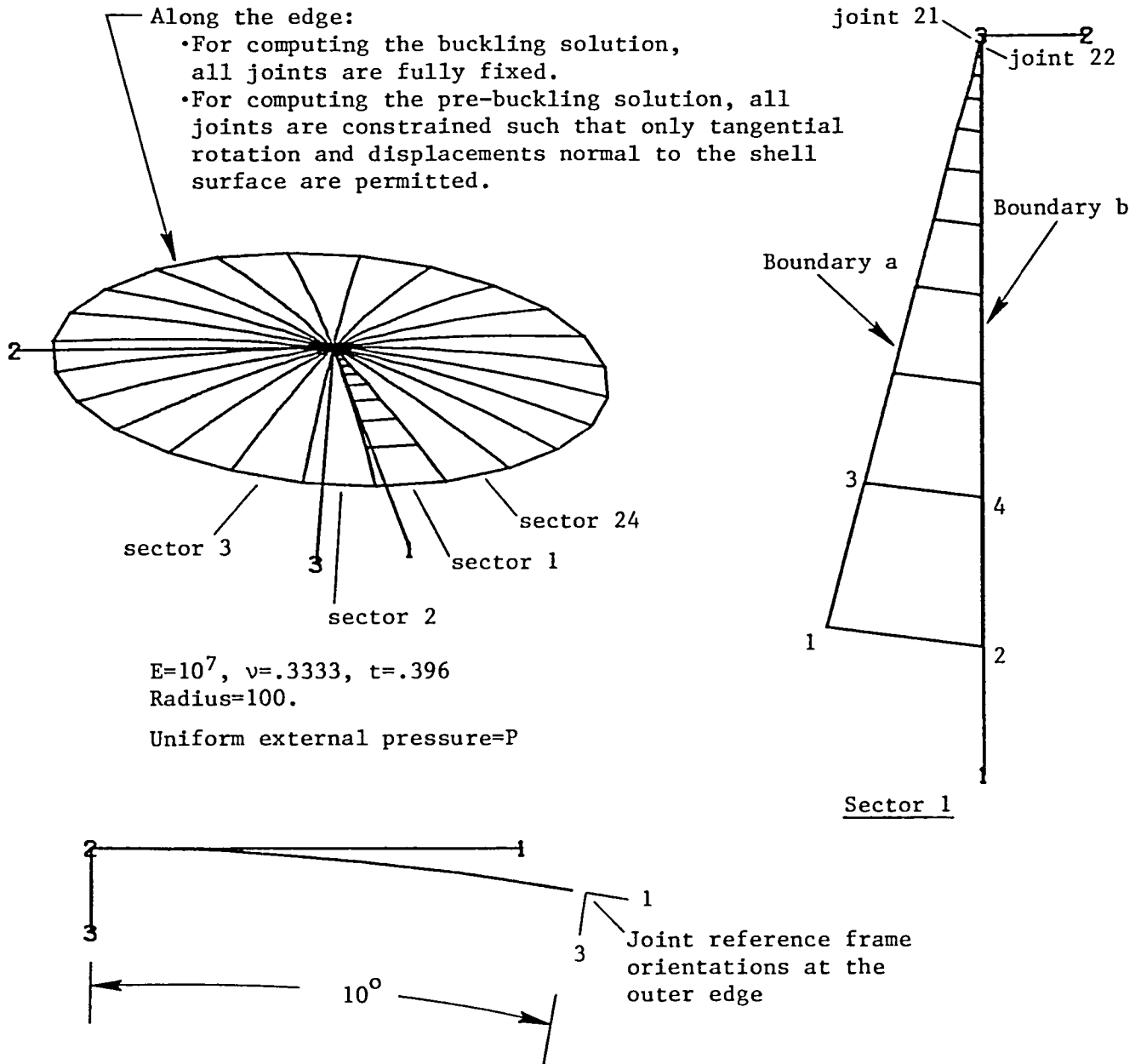
ANTI-SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

HARMONICS:

| MODE | 6 | 7 | 8 | 9 |
|------|----------|----------|----------|----------|
| 1 | -.678-05 | -.222-05 | -.362-05 | -.103-04 |

4.4.3 CS: BUCKLING OF A 10 DEGREE SECTOR OF A SPHERICAL SHELL DUE TO PRESSURE LOADING

The runstream for the problem described below is shown on the following page. The computed results agree exactly with those obtained with the quarter model described in Volume 3 of the EAL Reference Manual. Sample printout for the cyclic symmetry solution is shown on pages 4.4.3-2 and 4.4.3-3.



```

*XQT U1
*(29 SPHERE DEFINITION)
  1.+7 .3333 .1 .1-4 .396 100. 15. 10. 10
$ E NU RHO ALPHA T RADIUS THETA GAMMA ELEMENTS
*DCALL(MODEL BUILDER)
*XQT U1
*(CONSTRAINTS PRE)
  ZERO 2 4 6: 1,22: ZERO 1: 1,2
*(CONSTRAINTS)
  ZERO 1 2 3 4 5 6: 1,2
*(LOADS)
  ALPHA: CASE TITLE: 1'UNIT EXTERNAL PRESSURE
  TABLE: NODAL PRESSURE: J=1,22: 1.
*XQT AUS
  TABLE(NJ=4,TYPE=0): 5 HARMONICS: DDATA=1: RJ=1,4: 0
  TABLE(NJ=1,TYPE=0): 5 BACK SECTORS: J=1: 1
*XQT U1
*(OPTIONS)
  !NSECTORS=24: !INIT=6: !NREQ=4: !NVECTORS=4: !ERCK=0: !PROB='BUCK
  !NEVALS=4
*CALL(CS)

```

CYCLIC SYMMETRY BUCKLING EIGENVALUES FOLLOW:

| MODE | HARMONIC NUMBER | EIGENVALUE |
|------|--------------------|------------|
| 1 | 0 | .2383+03 |
| 2 | 1 | .2473+03 |
| 3 | 1 | .2473+03 |
| 4 | 2 | .2488+03 |
| 5 | 2 | .2488+03 |
| 6 | 3 | .2850+03 |
| 7 | 3 | .2850+03 |
| 8 | 1 | .3533+03 |
| 9 | 1 | .3533+03 |
| 10 | 0 | .4012+03 |
| 11 | 2 | .4184+03 |
| 12 | 2 | .4184+03 |
| 13 | 3 | .5159+03 |
| 14 | 3 | .5159+03 |
| 15 | 0 | .6595+03 |
| 16 | 0 | .9940+03 |

EIGENVALUES

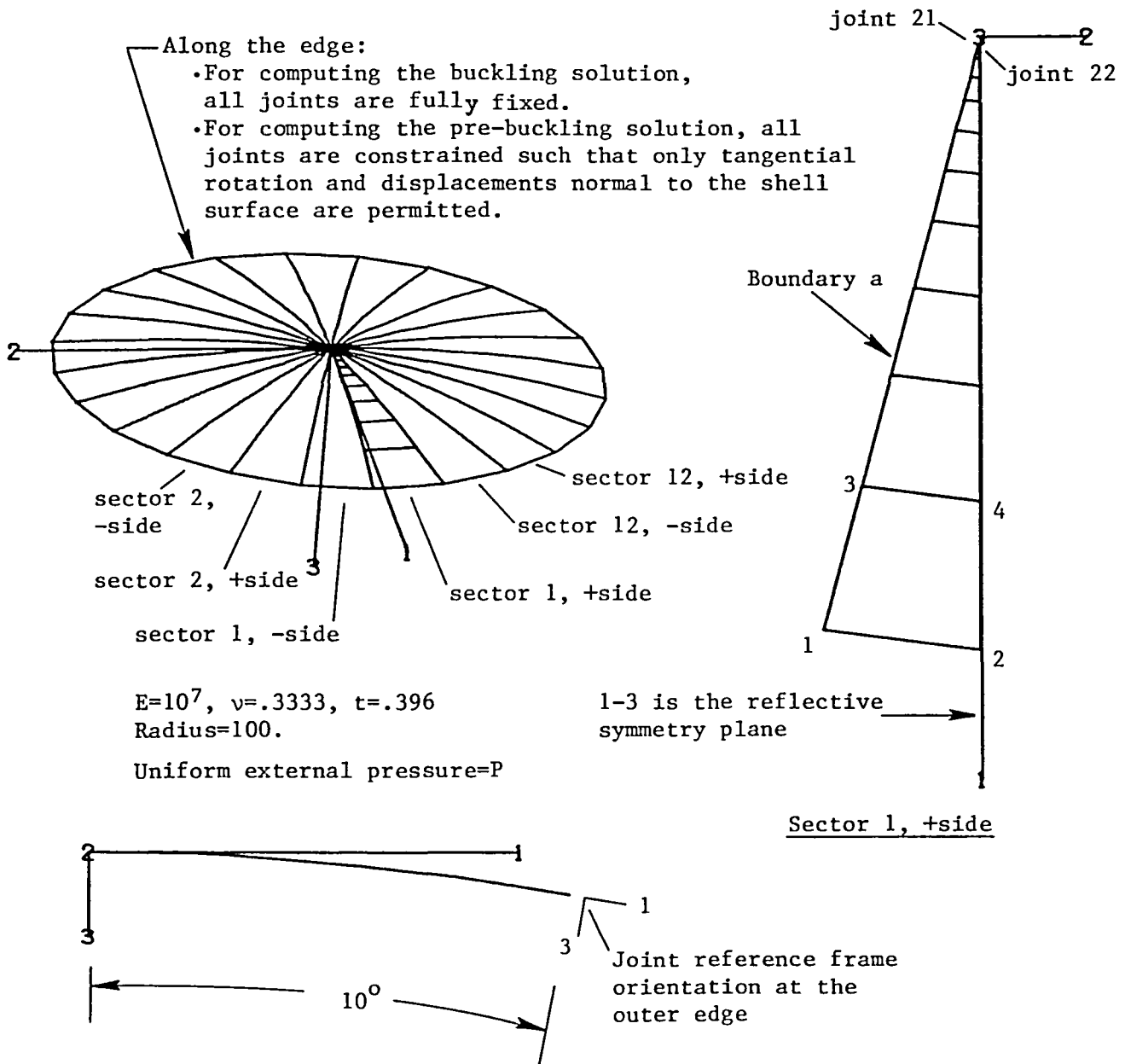
| HARMONICS: | | | | |
|------------|---------|---------|---------|---------|
| MODE | 0 | 1 | 2 | 3 |
| 1 | .238+03 | .247+03 | .249+03 | .285+03 |
| 2 | .401+03 | .247+03 | .249+03 | .285+03 |
| 3 | .660+03 | .353+03 | .418+03 | .516+03 |
| 4 | .994+03 | .353+03 | .418+03 | .516+03 |

EIGENVALUE CONVERGENCE MATRIX

| HARMONICS: | | | | |
|------------|----------|----------|----------|----------|
| MODE | 0 | 1 | 2 | 3 |
| 1 | .000 | -.154-07 | .000 | .000 |
| 2 | .000 | -.154-06 | -.307-07 | .000 |
| 3 | -.116-07 | -.756-07 | -.912-08 | -.166-05 |
| 4 | -.967-04 | -.311-04 | -.908-04 | -.422-04 |

4.4.4 CSR: BUCKLING OF A 10 DEGREE SECTOR OF A SPHERICAL SHELL DUE TO PRESSURE LOADING

The runstream for the problem described below is shown on the following page. The computed results agree exactly with those obtained with the quarter model described in Volume 3 of the EAL Reference Manual. Sample printout from the cyclic symmetry + reflective symmetry solution is shown on pages 4.4.4-2 and 4.4.4-3.




```

*XQT U1
*(29 SPHERE DEFINITION)
  1.+7 .3333 .1 .1-4 .396 100. 15. 10. 10
$ E NU RHO ALPHA T RADIUS THETA GAMMA ELEMENTS
*DCALL(MODEL BUILDER)
*XQT U1
*(CONSTRAINTS PRE)
  ZERO 2 4 6: 1,22: ZERO 1: 1,2
*(CONSTRAINTS)
  ZERO 1 2 3 4 5 6: 1,2
*(LOADS)
  ALPHA: CASE TITLE: 1'UNIT EXTERNAL PRESSURE
  TABLE: NODAL PRESSURE: J=1,22: 1.
*XQT AUS
  TABLE(NJ=4,TYPE=0): 5 HARMONICS: DDATA=1: RJ=1,4: 0
  TABLE(NJ=1,TYPE=0): 5 BACK SECTORS: J=1: 1
*XQT U1
*(OPTIONS)
  !NSECTORS=12: !RFLP=2: !PROB='BUCK
  !INIT=4: !NREQ=2: !NVECTORS=2: !NEVALS=2: !ERCK=0
*CALL(CSR)

```

CYCLIC SYMMETRY BUCKLING EIGENVALUES FOLLOW:

| MODE | HARMONIC NUMBER | REFLECTIVE BND. COND. | EIGENVALUE |
|------|--------------------|--------------------------|------------|
| 1 | 0 | SYMM | .2379+03 |
| 2 | 1 | SYMM | .2471+03 |
| 3 | 1 | ASYM | .2471+03 |
| 4 | 2 | SYMM | .2488+03 |
| 5 | 2 | ASYM | .2488+03 |
| 6 | 3 | SYMM | .2853+03 |
| 7 | 3 | ASYM | .2853+03 |
| 8 | 1 | SYMM | .3517+03 |
| 9 | 1 | ASYM | .3517+03 |
| 10 | 0 | SYMM | .3996+03 |
| 11 | 2 | SYMM | .4172+03 |
| 12 | 2 | ASYM | .4172+03 |
| 13 | 3 | ASYM | .5160+03 |
| 14 | 3 | SYMM | .5160+03 |
| 15 | 0 | ASYM | .1483+04 |
| 16 | 0 | ASYM | .2744+04 |

EIGENVALUES

SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

| HARMONICS: | | | | |
|------------|---------|---------|---------|---------|
| MODE | 0 | 1 | 2 | 3 |
| 1 | .238+03 | .247+03 | .249+03 | .285+03 |
| 2 | .400+03 | .352+03 | .417+03 | .516+03 |

EIGENVALUE CONVERGENCE MATRIX

SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

| HARMONICS: | | | | |
|------------|----------|----------|----------|----------|
| MODE | 0 | 1 | 2 | 3 |
| 1 | .000 | -.347-06 | .000 | .000 |
| 2 | -.537-04 | -.151-04 | -.420-04 | -.161-04 |

EIGENVALUES

ANTI-SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

| HARMONICS: | | | | |
|------------|---------|---------|---------|---------|
| MODE | 0 | 1 | 2 | 3 |
| 1 | .148+04 | .247+03 | .249+03 | .285+03 |
| 2 | .274+04 | .352+03 | .417+03 | .516+03 |

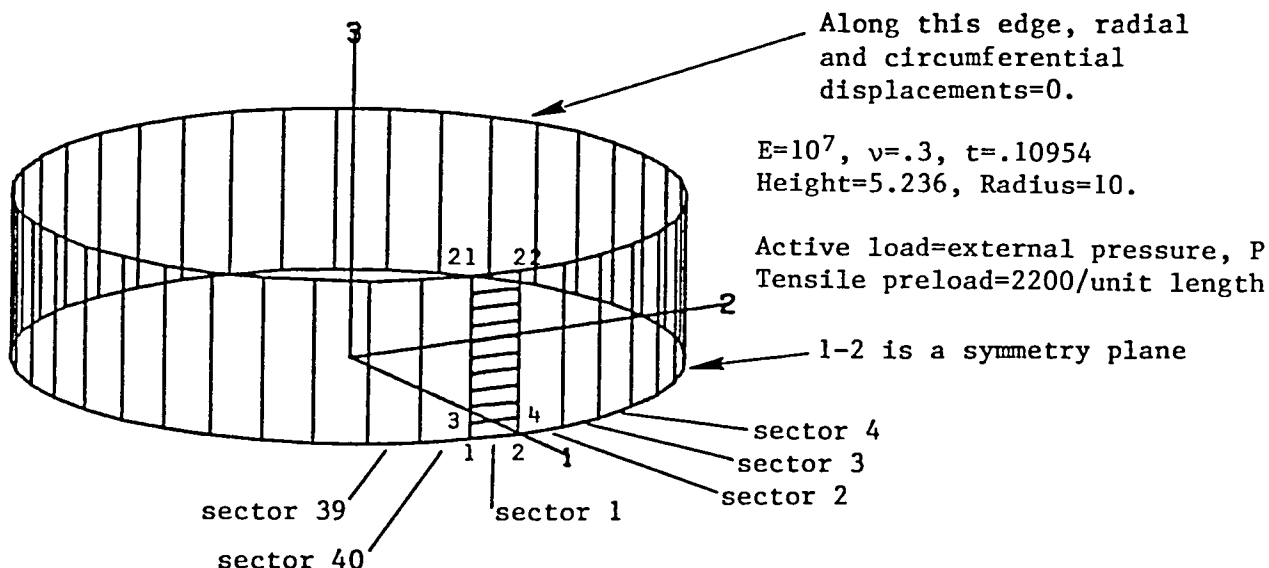
EIGENVALUE CONVERGENCE MATRIX

ANTI-SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

| HARMONICS: | | | | |
|------------|----------|----------|----------|----------|
| MODE | 0 | 1 | 2 | 3 |
| 1 | .000 | -.136-04 | -.153-07 | -.134-07 |
| 2 | -.688-04 | .000 | -.789-04 | -.172-04 |

4.4.5 CS: BUCKLING OF A PRE-TENSIONED CYLINDRICAL SHELL DUE TO PRESSURE LOADING

The runstream for the problem described below is shown at the bottom of the page. The computed buckling pressure of 162.3 agrees exactly with the solution obtained with the quarter model described in Volume 3 of the EAL Reference Manual. Sample printout from the cyclic symmetry solution is shown on page 4.4.5-2.



```
*XQT U1
*(CYLINDER DEFINITION)
  10.+6 .3 .1 1.-5 .10954 10. 5.236 9. 10
$ E NU RHO ALPHA T RADIUS HEIGHT THETA ELEMENTS
*DCALL(MODEL BUILDER)
*XQT U1
*(LOADS PRE)
  ALPHA: CASE TITLE: 1'PRETENSION
  SYSVEC: APPL FORC: I=3: J=21,22: 1727.9
*(CONSTRAINTS PRE)
  SYMMETRY PLANE=3: ZERO 2 4 6: 1,22
*(LOADS)
  ALPHA: CASE TITLE 2: 1'UNIT EXTERNAL PRESSURE
  TABLE: NODAL PRESSURES 2: J=1,22: -1.
*(CONSTRAINTS)
  SYMMETRY PLANE=3: ZERO 1 2 6: 21,22
*XQT AUS
  TABLE(NJ=3,TYPE=0): 5 HARMONICS: J=1,3: 7: 8: 9
  TABLE(NJ=1,TYPE=0): 5 BACK SECTORS: J=1: 1
*XQT U1
*(OPTIONS)
. !NSECTORS=40: !INIT=4: !NREQ=2: !NVECT=2: !NEVAL=2: !PROB='BUCK
*CALL(CS)
```

CYCLIC SYMMETRY BUCKLING EIGENVALUES FOLLOW:

| HARMONIC | | |
|----------|--------|------------|
| MODE | NUMBER | EIGENVALUE |
| 1 | 8 | .1623+03 |
| 2 | 8 | .1623+03 |
| 3 | 9 | .1631+03 |
| 4 | 9 | .1631+03 |
| 5 | 7 | .1845+03 |
| 6 | 7 | .1845+03 |

EIGENVALUES

| HARMONICS: | | | |
|------------|---------|---------|---------|
| MODE | 7 | 8 | 9 |
| 1 | .184+03 | .162+03 | .163+03 |
| 2 | .184+03 | .162+03 | .163+03 |

EIGENVALUE CONVERGENCE MATRIX

| HARMONICS: | | | |
|------------|----------|----------|----------|
| MODE | 7 | 8 | 9 |
| 1 | -.124-05 | -.119-05 | -.191-05 |
| 2 | -.121-05 | -.112-05 | -.200-05 |

CYCLIC SYMMETRY BUCKLING EIGENVALUES FOLLOW:

| MODE | HARMONIC NUMBER | REFLECTIVE BND. COND. | EIGENVALUE |
|------|--------------------|--------------------------|------------|
| 1 | 8 | ASYM | .1623+03 |
| 2 | 8 | SYMM | .1623+03 |
| 3 | 9 | ASYM | .1631+03 |
| 4 | 9 | SYMM | .1631+03 |
| 5 | 7 | ASYM | .1845+03 |
| 6 | 7 | SYMM | .1845+03 |

EIGENVALUES

SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

HARMONICS:

| MODE | 7 | 8 | 9 |
|------|---------|---------|---------|
| 1 | .184+03 | .162+03 | .163+03 |

EIGENVALUE CONVERGENCE MATRIX

SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

HARMONICS:

| MODE | 7 | 8 | 9 |
|------|----------|----------|----------|
| 1 | -.511-05 | -.300-05 | -.526-05 |

EIGENVALUES

ANTI-SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

HARMONICS:

| MODE | 7 | 8 | 9 |
|------|---------|---------|---------|
| 1 | .184+03 | .162+03 | .163+03 |

EIGENVALUE CONVERGENCE MATRIX

ANTI-SYMMETRIC CONSTRAINT ON THE REFLECTIVE PLANE

HARMONICS:

| MODE | 7 | 8 | 9 |
|------|----------|----------|----------|
| 1 | -.371-05 | -.601-05 | -.137-04 |

4.5.1 CS: RESTARTED ANALYSIS, RAIL WHEEL EXAMPLE, STATIC ANALYSIS, VIBRATIONAL MODES

The runstream is shown below for computing in a single execution both the static analysis and the vibrational analysis described in Sections 4.2.3 and 4.3.5. The static solution computations utilize the harmonic stiffness matrices and factored harmonic stiffness matrices created during the vibrational solution. See Section 2.7 for instructions for restarted executions.

```
*XQT U1
*(RAIL OPTIONS)
!NTHETA=4: !THETA=45.
*(ISOTROPIC SOLIDS)$ E NU RHO OTHERS
J=1: 29.+6 .3 .28 0. 0. 0.
*DCALL(RAIL WHEEL)
*XQT AUS
TABLE(NJ=39,TYPE=0): JA: DDATA=1: RJ=1,39: 1
TABLE(NJ=39,TYPE=0): JB: DDATA=1: RJ=1,39: 157
$
$ COMPUTE VIBRATIONAL MODES:
*XQT U1
*(CONSTRAINTS)
ZERO 1 2 3: 4,6: 160,162: "JTS"
*(OPTIONS)
!NSECTORS=8: !G=386.
!INIT=10: !NREQ=8: !NVECTORS=6: !NEVALS=6: !NDYN=20: !VPRT=0
*CALL(CS)
$
$ COMPUTE STATIC SOLUTION:
*XQT AUS
TABLE(NI=18,NJ=1,TYPE=4): 5 TITLE FORC: J=1
'RAIL WHEEL, POINT LOADS APPLIED AT STATION 1
TABLE(NJ=1,TYPE=0): 5 SECT FORC: J=1: 1
SYSVEC: 5 APPL FORC
I=1: J= 28: 29: 30: 33: 36: 39
-750.: -500.: -250.: -1000.: -1000.: -500.
I=3: J= 37: 38: 39
600.: 1200.: 600.
*XQT U1
*(OPTIONS)
!PROB='STAT
*(ES OPTIONS)
NODES=0: D3D=3
*CALL(CS RESTART)
```

4.5.2 CSR: RESTARTED ANALYSIS, RAIL WHEEL EXAMPLE, STATIC ANALYSIS, VIBRATIONAL MODES

The runstream is shown below for computing in a single execution both the static analysis and the vibrational analysis described in Sections 4.2.4 and 4.3.6. The static solution computations utilize the harmonic stiffness matrices and factored harmonic stiffness matrices created during the vibrational solution. See Section 2.7 for instructions for restarted executions.

```
*XQT U1
*(RAIL OPTIONS)
  !NTHETA=2: !THETA=22.5
*(ISOTROPIC SOLIDS)$   E      NU      RHO      OTHERS
  J=1:                29.+6   .3      .28      0. 0. 0.
*DCALL(RAIL WHEEL)
*XQT AUS
  TABLE(NJ=39,TYPE=0): JA: DDATA=1: RJ=1,39: 79
$
$ COMPUTE VIBRATIONAL MODES:
*XQT U1
*(CONSTRAINTS)
  ZERO 1 2 3: 4,6: "JTS"
*(OPTIONS)
  !NSECTORS=8: !G=386.: !RFLP=2
  !INIT=6: !NREQ=4: !NVECTORS=3: !NEVALS=3: !NDYN=20: !VPRT=0
*CALL(CSR)
$
$ COMPUTE STATIC ANALYSIS:
*XQT AUS
  TABLE(NI=18,NJ=1,TYPE=4): 5 TITLE FORC: J=1
    'RAIL WHEEL, POINT LOADS APPLIED AT STATION 1
  TABLE(NJ=1,TYPE=0): 5 SECT FORC: J=1: 1
  SYSVEC: 5 F+ FORC
    I=1: J=   28:   29:   30:   33:   36:   39
           -750.: -500.: -250.: -1000.: -1000.: -500.
    I=3: J=   37:   38:   39
           600.: 1200.: 600.
  OUTLIB=5: INLIB=5: F- FORC= UNION(0. F+)
*XQT U1
*(OPTIONS)
  !PROB='STAT
*(ES OPTIONS)
  NODES=0: D3D=3
*CALL(CSR RESTART)
```

5. SUMMARY OF CYCLIC SYMMETRY COMMAND RUNSTREAMS

Command runstream element names and functions are tabulated below. Elements with a first word of CS in their name pertain to cyclically symmetrical structures with no plane of reflective symmetry. A first word of CSR in the element name pertains to cyclically symmetrical structures with a plane of reflective symmetry.

| <u>Element Name</u> | | | | <u>Function</u> |
|---------------------|---------|---|---|--|
| CS | XXXX | 1 | 1 | Driver procedures for the initial execution for a model. Directs the analysis by calling the appropriate sub-procedures. |
| CSR | XXXX | 1 | 1 | |
| CS | RESTART | 1 | 1 | Directs the analysis for a restarted execution. |
| CSR | RESTART | 1 | 1 | |
| CS | K+KG | 1 | 1 | For both CS and CSR models, this procedure computes the main sector stiffness matrix, K+KG, for preload. |
| CS | DEFAULT | 1 | 1 | Creates default register values, |
| CSR | DEFAULT | 1 | 1 | |
| CS | STORE | 1 | 1 | Stores registers in Lib.1 that are required for a restarted execution. |
| CSR | STORE | 1 | 1 | |
| CS | FETCH | 1 | 1 | Fetches registers stored by (CS STORE) and (CSR STORE) |
| CSR | FETCH | 1 | 1 | |
| CS | STEP | 1 | 1 | (1) Creates data sets containing lists of boundary and interior joints. (2) Directs computation of sector stiffness, mass, and geometric stiffness matrices. Spectral shifts and the adding of rigid masses are included. |
| CSR | STEP | 1 | 1 | |
| CSR | CONS | 1 | 1 | Creates symmetric and anti-symmetric constraint conditions. |
| CS | JSEQ | 1 | 1 | Computes the single sector joint sequencing array to insure that the sector matrices are properly formatted for subsequent procedures. |
| CSR | JSEQ | 1 | 1 | |
| CS | DCK | 1 | 1 | Checks for errors in the input data runstream elements and data sets. |
| CS | DCK | 2 | 1 | |
| CSR | DCK | 1 | 1 | |
| CSR | DCK | 2 | 1 | |

| <u>Element Name</u> | | | | <u>Function</u> |
|---------------------|-------|---|---|---|
| CS | LPREP | 1 | 1 | Creates applied force related data sets for subsequent static analysis. |
| CSR | LPREP | | | |
| CS | MAIN | 1 | 1 | Directs the computation of each harmonic solution. |
| CSR | MAIN | 1 | 1 | |
| CS | INIT | 1 | 1 | Creates registers and data sets that do not change with the harmonic number, k. |
| CS | PLOT | 1 | 1 | Controls production of the pseudo model for plotting the entire structure. |
| CS | JPLT | 1 | 1 | Creates joint locations for the pseudo plot model. |
| CS | JPLT | 1 | 1 | Creates displacement vectors for the pseudo plot model. |

The following command runstream elements perform functions for a given circumferential harmonic, k:

| <u>Element Name</u> | | | | <u>Function</u> |
|---------------------|------|---|---|---|
| CS | TAB | 1 | 1 | Sets up initial TAB data sets, including JDF1, JREF, JSEQ, and CON. |
| CSR | TAB | 1 | 1 | |
| CS | MAPS | 1 | 1 | (1) Constructs list of joints used for subsequent data transfers, and (2) Constructs the harmonic constraint arrays. |
| CSR | MAPS | 1 | 1 | |
| CS | MKKG | 1 | 1 | Directs computation of harmonic mass, stiffness, and geometric stiffness matrices. |
| CSR | MKKG | 1 | 1 | |
| CS | TDEM | 1 | 1 | Constructs the harmonic diagonal mass matrix. |
| CSR | TDEM | 1 | 1 | |
| CS | TK | 1 | 1 | Constructs a harmonic system matrix in labeled element format. |
| CSR | TK | 1 | 1 | |
| CSR | CT | 1 | 1 | Constructs data sets used in the CSR solution. |
| CS | EIG | 1 | 1 | Computes the harmonic eigensolution. |
| CSR | EIG | 1 | 1 | |
| CS | STAT | 1 | 1 | Computes the harmonic static solution. |
| CSR | STAT | 1 | 1 | |

| <u>Element Name</u> | | | | <u>Function</u> |
|---------------------|------|---|---|---|
| CS | FOUR | 1 | 1 | Constructs the Fourier symmetrical components of motion corresponding to the harmonic solution. |
| CSR | FOUR | 1 | 1 | |
| CS | SECT | 1 | 1 | Constructs sector eigenvectors. |
| CSR | SECT | 1 | 1 | |
| CS | SECT | 2 | 1 | Constructs sector static displacement vectors. |
| CSR | SECT | 2 | 1 | |
| CS | EVMX | 1 | 1 | Constructs eigenvalue solution matrices. NI = harmonics, NJ = modes. |
| CSR | EVMX | 1 | 1 | |
| CS | EVPR | 1 | 1 | Directs printing of solution eigenvalues. |
| CSR | EVPR | 1 | 1 | |
| CS | EVPR | 2 | 1 | Prints a single eigenvalue matrix. |
| CS | VPRT | 1 | 1 | Prints solution eigenvectors. |
| CSR | VPRT | 1 | 1 | |
| CS | VPRT | 2 | 1 | Prints static displacement solution vectors. |
| CSR | VPRT | 2 | 1 | |

6. THEORY

Section 6.1 presents the theoretical background for cyclically symmetrical structures with no plane of reflective symmetry. Section 6.2 presents the theoretical background for cyclically symmetrical structures with a plane of reflective symmetry.

Equation numbering in this section begins with Eq.(1). All equation references pertain to equations that are contained in Section 6.

6.1 THEORETICAL BASIS OF CS

The following notation will be used:

n = number of sectors

K = stiffness matrix of a single sector (same for all sectors)

U_{ai} = motion vector, boundary a, sector i

U_{bi} = motion vector, boundary b, sector i

U_{oi} = motion vector, non-boundary portion of sector i

$U_i = \begin{bmatrix} U_{ai} \\ U_{bi} \\ U_{oi} \end{bmatrix}$ = motion vector, sector i

F_{ai} = applied force vector, boundary a, sector i

F_{bi} = applied force vector, boundary b, sector i

F_{oi} = applied force vector, non-boundary portion of sector i

$F_i = \begin{bmatrix} F_{ai} \\ F_{bi} \\ F_{oi} \end{bmatrix}$ = applied force vector, sector i

λ = system eigenvalue

System equations for static analysis may be written in the following form:

$$\begin{bmatrix} K & & & \\ & K & & \\ & & \cdot & \\ & & & \cdot \\ & & & & K \end{bmatrix} \begin{bmatrix} U_1 \\ U_2 \\ \cdot \\ \cdot \\ U_n \end{bmatrix} = \begin{bmatrix} F_1 \\ F_2 \\ \cdot \\ \cdot \\ F_n \end{bmatrix}, \text{ or } \bar{K} U = F, \quad (1)$$

subject to the inter-sector compatibility requirements,

$$U_{bi} = U_{a,i-1}, \text{ for } i = 1 \text{ through } n-1, \text{ and} \quad (2)$$

$$U_{bn} = U_{a1}$$

As discussed in Reference 1, the following transformation of coordinates may be used to reformulate Eqs.(1) and (2) as a sequence of uncoupled static analysis problems of much lower order:

$$U_i = \sum_{k=0}^m Q_{kc} \cos(i-1) \frac{2\pi k}{n} + Q_{ks} \sin(i-1) \frac{2\pi k}{n}, \quad (3)$$

$$m = n/2 \text{ if } n \text{ is even,}$$

$$= (n-1)/2 \text{ if } n \text{ is odd.}$$

¹ Mac Neal, R. H., R. L. Harder, and J. B. Mason, NASTRAN Cyclic Symmetry Capability, NASTRAN Users Experiences 3rd Colloq., Langley Research Center, Hampton, Virginia, 395-421 (1973), NASA TECh. Memo, NASA TM X-2893.

Performing the transformation of coordinates indicated by Eq.(3) and Eq.(1) yields the following system equations:

$$\bar{K} Q = P, \quad (4)$$

where

$$Q = [Q_{0c} \quad Q_{0s} \quad Q_{1c} \quad Q_{1s} \cdot \cdot \cdot Q_{mc} \quad Q_{ms}]^t, \text{ and}$$

$$P = [P_{0c} \quad P_{0s} \quad P_{1c} \quad P_{1s} \cdot \cdot \cdot P_{mc} \quad P_{ms}]^t.$$

Expressions for P_{kc} and P_{ks} are,

$$P_{kc} = \begin{bmatrix} P_{akc} \\ P_{bkc} \\ P_{okc} \end{bmatrix} = A_k \sum_{i=1}^n \begin{bmatrix} F_{ai} \\ F_{bi} \\ F_{oi} \end{bmatrix} \cos(i-1) \frac{2\pi k}{n}, \text{ and}$$

$$P_{ks} = \begin{bmatrix} P_{aks} \\ P_{bks} \\ P_{oks} \end{bmatrix} = A_k \sum_{i=1}^n \begin{bmatrix} F_{ai} \\ F_{bi} \\ F_{oi} \end{bmatrix} \sin(i-1) \frac{2\pi k}{n}, \quad (5)$$

where $A_k = 1/n$ for $k=0$ and $k=n/2$, and $A_k = 2/n$ for all other values of k .

Note that the stiffness matrix of Eq.(4) is the same as the stiffness matrix of Eq.(1).

Inter-sector compatibility requirements must now be imposed on Eq.(4).

In the following,

$$Q_{kc} = \begin{bmatrix} Q_{akc} \\ Q_{bkc} \\ Q_{okc} \end{bmatrix}, \quad Q_{ks} = \begin{bmatrix} Q_{aks} \\ Q_{bks} \\ Q_{oks} \end{bmatrix}, \quad (6)$$

where a, b, and o subscripts have the same meaning as in U_{ai} , U_{bi} , and U_{oi} .

For inter-sector compatibility, we substitute Eqs.(6) and (3) into Eq.(2) to obtain

$$\begin{bmatrix} C_k & S_k \\ -S_k & C_k \end{bmatrix} \begin{bmatrix} Q_{akc} \\ Q_{aks} \end{bmatrix} = \begin{bmatrix} Q_{bkc} \\ Q_{bks} \end{bmatrix}, \quad (7)$$

where $C_k = \cos(2\pi k/n)$, $S_k = \sin(2\pi k/n)$, and $k = 0$ through m .

Eq.(7) indicates that coupling exists only for symmetrical components of the same circumferential harmonic.

Writing the sector stiffness matrix in partitions as

$$K = \begin{bmatrix} K_{aa} & K_{ab} & K_{ao} \\ & K_{bb} & K_{bo} \\ \text{Symmetric} & & K_{oo} \end{bmatrix},$$

and imposing the compatibility requirements of Eq.(7) onto Eq.(4) yields m uncoupled equations of the form:

$$\bar{K}_k \begin{bmatrix} Q_{okc} \\ Q_{akc} \\ Q_{oks} \\ Q_{aks} \end{bmatrix} = \begin{bmatrix} P_{okc} \\ P_{akc} + C_k \cdot P_{bkc} - S_k \cdot P_{bks} \\ P_{oks} \\ P_{aks} + S_k \cdot P_{bkc} + C_k \cdot P_{bks} \end{bmatrix}, \quad \text{where} \quad (8)$$

$$\bar{K}_k = \begin{bmatrix} K_{oo} & K_{oa} + C_k \cdot K_{ob} & 0 & S_k \cdot K_{ob} \\ K_{aa} + K_{bb} + C_k (K_{ab} + K_{ba}) & -S_k \cdot K_{ab} & S_k (K_{ab} - K_{ba}) & \\ K_{oo} & K_{oa} + C_k \cdot K_{ob} & & \\ \text{Symmetric} & & K_{aa} + K_{bb} + C_k (K_{ab} + K_{ba}) & \end{bmatrix} \quad (9)$$

\bar{K}_k is called the k^{th} harmonic stiffness matrix. Note that for $k=0$ or $k=n/2$, $S_k=0$, and \bar{K}_k reduces two equal decoupled partitions each of which is half the order of \bar{K}_k .

In the cyclic symmetry procedures, CS, static solutions are computed as follows:

1. For each value of k ,
 - o The applied loads are factored into their harmonic components according to Eqs.(5),
 - o The harmonic stiffness matrix is formed according to Eq.(9),
 - o Eq.(8) is used to compute Q_{okc} , Q_{akc} , Q_{oks} , and Q_{aks} , and
 - o Eq.(7) is used to compute Q_{bkc} and Q_{bks} , and Q_{kc} and Q_{ks} are formed according to Eq.(6).
2. Individual sector displacement vectors are computed by substituting Q_{kc} and Q_{ks} into Eq.(3).

For a general applied loading, all possible values of k (0 through m) are required for an exact solution. However, provisions are included in CS for truncating the solution to a specified subset of harmonics.

For cyclic symmetry eigenvalue problems, system equations are written as:

$$\begin{aligned} \lambda \bar{M} U - \bar{K} U &= 0, \text{ for undamped vibration, and} \\ \lambda \bar{KG} U + \bar{K} U &= 0, \text{ for buckling.} \end{aligned} \tag{10}$$

The system mass matrix \bar{M} and geometric stiffness matrix \bar{KG} have the same form as \bar{K} in Eq.(1). Performing the transformation of coordinates indicated by Eq.(3) and imposing the compatibility requirements of Eq.(7) on Eqs.(10) yields M uncoupled eigenvalue problems of the following form:

$$\lambda \bar{M}_k \bar{Q}_k - \bar{K}_k \bar{Q}_k = 0, \text{ for vibration, and} \quad (11)$$

$$\lambda \bar{KG}_k \bar{Q}_k + \bar{K}_k \bar{Q}_k = 0, \text{ for buckling}$$

where

$$\bar{Q}_k = \begin{bmatrix} Q_{okc} \\ Q_{akc} \\ Q_{oks} \\ Q_{aks} \end{bmatrix}$$

\bar{KG}_k has the same form as \bar{K}_k in Eq.(9). For a consistent mass matrix formulation, \bar{M}_k has the same form as \bar{K}_k . For a diagonal mass matrix

$$\bar{M}_k = \begin{bmatrix} M_{oo} & & & \\ & (M_{aa} + M_{bb}) & & \\ & & M_{oo} & \\ & & & (M_{aa} + M_{bb}) \end{bmatrix} \quad (12)$$

The CS procedures compute eigenvalue solutions according to Eqs.(11) for user specified values of k (0 through m). Back transformation for the corresponding sector eigenvectors is performed by successive use of Eqs.(7), (6), and (3).

6.2 THEORETICAL BASIS OF CSR

For cylically symmetrical structures in which each sector possesses a reflective plane of symmetry, a finite element model of a symmetric half of one sector is used to compute static, vibrational, and buckling solutions for the complete structure.

The following terminology will be used:

- +side = that half of a sector for which the finite model is supplied.
- side = the reflective half of a sector,
- sector = the +side and -side together make up 1 sector.

The following notation will be used:

n = number of sectors in the complete structure,

K = stiffness matrix of the +side of a sector
(same for both sides of all sectors)

U_{ai}^+ = motion vector, boundary a, +side of sector i,

U_{oi}^+ = motion vector, non-boundary portion of the +side of sector i,

$U_i^+ = \begin{bmatrix} U_{oi}^+ \\ U_{ai}^+ \end{bmatrix}$ = motion vector, +side of sector i

F_{ai}^+ = applied force vector, boundary a, +side of sector i

F_{oi}^+ = applied force vector, non-boundary portion of the +side of sector i,

$F_i^+ = \begin{bmatrix} F_{oi}^+ \\ F_{ai}^+ \end{bmatrix}$ = applied force vector, +side of sector i

$U_{ai}^-, U_{oi}^-, U_i^-, F_{ai}^-, F_{oi}^-, F_i^-$ = motion and applied force vectors, -side of sector i. These vectors are defined relative to left-handed joint reference frames, see Fig.3, Section 2.2,

λ = system eigenvalue

System equations for static analysis may be written in the following form:

$$\begin{bmatrix} K & & & \\ & K & & \\ & & \ddots & \\ & & & K \\ & & & & K \end{bmatrix} \begin{bmatrix} U_1^+ \\ U_1^- \\ \vdots \\ U_n^+ \\ U_n^- \end{bmatrix} = \begin{bmatrix} F_1^+ \\ F_1^- \\ \vdots \\ F_n^+ \\ F_n^- \end{bmatrix}, \text{ or } \bar{K} U = F, \quad (13)$$

Subject to the inter-sector compatibility requirements

$$\begin{aligned} U_{a,i+1}^+ &= \bar{T} \cdot U_{ai}^-, \text{ for } i=1 \text{ through } n-1, \text{ and} \\ U_{a,1}^+ &= \bar{T} \cdot U_{an}^-. \end{aligned} \quad (14)$$

Using cylindrical joint reference frames for a structure in which the global 3 axis is the axis of cyclic symmetry, \bar{T} of Eq.(14) takes the following form:

$$\bar{T} = \begin{bmatrix} 1 & & & & \\ & -1 & & & \\ & & 1 & & \\ & & & -1 & \\ & & & & 1 \\ & & & & & -1 \end{bmatrix}$$

Transformations for reflective symmetry may be written as

$$\begin{aligned} U_i^+ &= U_i^s + U_i^a, \text{ and} \\ U_i^- &= U_i^s - U_i^a, \end{aligned} \quad (15)$$

where

$$\begin{aligned} U_i^s &= \text{motion vector, symmetric deformation, sector } i, \text{ and} \\ U_i^a &= \text{motion vector, anti-symmetric deformation, sector } i. \end{aligned}$$

Performing the transformation indicated by Eq.(15) on Eq.(13), yields

$$\begin{bmatrix} K & & & \\ & K & & \\ & & \ddots & \\ & & & K \\ & & & & K \end{bmatrix} \begin{bmatrix} U_1^s \\ U_1^a \\ \vdots \\ U_n^s \\ U_n^a \end{bmatrix} = \begin{bmatrix} F_1^s \\ F_1^a \\ \vdots \\ F_n^s \\ F_n^a \end{bmatrix}, \quad (16)$$

where

$$\begin{aligned} F_i^s &= \frac{1}{2}(F_i^+ + F_i^-), \text{ and} \\ F_i^a &= \frac{1}{2}(F_i^+ - F_i^-). \end{aligned} \quad (17)$$

As discussed in Reference 1, the following transformation of coordinates may be used to reformulate Eq.(16) as a sequence of uncoupled static analysis problems of much lower order:

$$\begin{aligned} U_i^s &= \sum_{k=0}^m Q_{kc}^s \cos(i-1) \frac{2\pi k}{n} + Q_{ks}^s \sin(i-1) \frac{2\pi k}{n}, \text{ and} \\ U_i^a &= \sum_{k=0}^m Q_{kc}^a \cos(i-1) \frac{2\pi k}{n} + Q_{ks}^a \sin(i-1) \frac{2\pi k}{n}, \end{aligned} \quad (18)$$

$$\begin{aligned} m &= n/2 \text{ if } n \text{ is even,} \\ &= (n-1)/2 \text{ if } n \text{ is odd.} \end{aligned}$$

Expressions for Q_{kc}^s , Q_{ks}^s , Q_{kc}^a , Q_{ks}^a are

$$\begin{aligned} Q_{kc}^s &= \begin{bmatrix} Q_{okc}^s \\ Q_{akc}^s \end{bmatrix}, & Q_{ks}^s &= \begin{bmatrix} Q_{oks}^s \\ Q_{aks}^s \end{bmatrix}, \\ Q_{kc}^a &= \begin{bmatrix} Q_{okc}^a \\ Q_{akc}^a \end{bmatrix}, & Q_{ks}^a &= \begin{bmatrix} Q_{oks}^a \\ Q_{aks}^a \end{bmatrix}, \end{aligned} \quad (19)$$

where o and a subscripts have the same meaning as in U_{ai}^+ and U_{oi}^+ .

Performing the transformation of coordinates indicated by Eqs.(18) and Eq.(16), yields the following system equations:

$$\bar{K} Q = P, \quad (20)$$

where

$$Q = \begin{bmatrix} Q_{0c}^s & Q_{0s}^s & Q_{0c}^a & Q_{0s}^a & \dots & Q_{mc}^s & Q_{ms}^s & Q_{mc}^a & Q_{ms}^a \end{bmatrix}^t, \quad \text{and} \quad (21)$$

$$P = \begin{bmatrix} P_{0c}^s & P_{0s}^s & P_{0c}^a & P_{0s}^a & \dots & P_{mc}^s & P_{ms}^s & P_{mc}^a & P_{ms}^a \end{bmatrix}^t.$$

Expressions for P_{kc}^s , P_{ks}^s , P_{kc}^a , and P_{ks}^a are,

$$P_{kc}^s = \begin{bmatrix} P_{okc}^s \\ P_{akc}^s \end{bmatrix} = A_k \sum_{i=1}^n \begin{bmatrix} F_{oi}^s \\ F_{ai}^s \end{bmatrix} \cos(i-1) \frac{2\pi k}{n},$$

$$P_{ks}^s = \begin{bmatrix} P_{oks}^s \\ P_{aks}^s \end{bmatrix} = A_k \sum_{i=1}^n \begin{bmatrix} F_{oi}^s \\ F_{ai}^s \end{bmatrix} \sin(i-1) \frac{2\pi k}{n}, \quad (22)$$

$$P_{kc}^a = \begin{bmatrix} P_{okc}^a \\ P_{akc}^a \end{bmatrix} = A_k \sum_{i=1}^n \begin{bmatrix} F_{oi}^a \\ F_{ai}^a \end{bmatrix} \cos(i-1) \frac{2\pi k}{n}, \quad \text{and}$$

$$P_{ks}^a = \begin{bmatrix} P_{oks}^a \\ P_{aks}^a \end{bmatrix} = A_k \sum_{i=1}^n \begin{bmatrix} F_{oi}^a \\ F_{ai}^a \end{bmatrix} \sin(i-1) \frac{2\pi k}{n},$$

where $A_k = 1/n$ for $k = 0$ and $k = n/2$, and $A_k = 2/n$ for all other values of k . Note that the stiffness matrix of Eq.(20) is the same as the stiffness matrix of Eq.(13).

Inter-sector compatibility requirements must now be imposed on Eq.(20).

Substituting Eqs.(15) into Eqs.(14) yields,

$$U_{a,i+1}^s + U_{a,i-1}^a = \bar{T} (U_{ai}^s - U_{ai}^a) \quad (23)$$

By substituting Eqs.(19) and (18) into Eqs.(23), we obtain the following inter-sector compatibility equations, for systems in which \bar{T} is a diagonal matrix with terms of +1 or -1.

$$S_k Q_{akc}^a - (C_k - \bar{T}) Q_{aks}^s = 0, \text{ and} \quad (24)$$

$$-S_k Q_{akc}^s + (C_k + \bar{T}) Q_{aks}^a = 0, \quad (25)$$

where

$$S_k = \sin \frac{2\pi k}{n},$$

$$C_k = \cos \frac{2\pi k}{n} \cdot (6 \times 6 \text{ identity matrix}), \text{ and}$$

$$k = 0 \text{ through } m.$$

Eqs.(24) and (25) are imposed on the system by introducing new coordinates, and such that:

$$Q_{aks}^s = S_k Q_x, \quad Q_{akc}^a = (C_k - \bar{T}) Q_x, \quad (26)$$

$$Q_{aks}^a = S_k Q_y, \quad Q_{akc}^s = (C_k + \bar{T}) Q_y. \quad (27)$$

Writing a sector +side stiffness matrix as,

$$K = \begin{bmatrix} K_{oo} & K_{oa} \\ \text{Sym} & K_{aa} \end{bmatrix},$$

and imposing the compatibility requirements of Eq.(26) onto Eq.(20) yields m uncoupled equations of the form:

$$\begin{bmatrix} K_{oo} & 0 & K_{oa} \cdot S_k \\ & K_{oo} & K_{oa} \cdot (C_k - \bar{T}) \\ \text{Sym} & K_{aa} \cdot S_k^2 + (C_k - \bar{T}) K_{aa} (C_k - \bar{T}) \end{bmatrix} \begin{bmatrix} Q_{oks}^s \\ Q_{okc}^a \\ Q_x \end{bmatrix} = \begin{bmatrix} P_{oks}^s \\ P_{okc}^a \\ S_k \cdot P_{aks}^s + (C_k - \bar{T}) P_{akc}^a \end{bmatrix}, \quad (28)$$

or $\bar{K}_{kx} \bar{Q}_{kx} = \bar{P}_{kx}.$

In Eq.(28), pre-and post-multiples of K_{oa} and K_{aa} by $(C_k - \bar{T})$ indicate that each (6×6) submatrix of K_{oa} and K_{aa} are operated on by $(C_k - \bar{T})$.

Imposing the compatibility requirements of Eq.(27) onto Eq.(20) yields a second set of m uncoupled equations of the form:

$$\begin{bmatrix} K_{oo} & 0 & K_{oa} \cdot (C_k + \bar{T}) \\ & K_{oo} & K_{oa} \cdot S_k \\ \text{Sym} & K_{aa} \cdot S_k^2 + (C_k + \bar{T})K_{aa} (C_k + \bar{T}) & \end{bmatrix} \begin{bmatrix} Q_{okc}^s \\ Q_{oks}^a \\ Q_y \end{bmatrix} = \begin{bmatrix} P_{okc}^s \\ P_{oks}^a \\ S_k \cdot P_{aks}^a + (C_k + \bar{T})P_{akc}^s \end{bmatrix}, \quad (29)$$

$$\text{or} \quad \bar{K}_{ky} \quad \bar{Q}_{ky} = \bar{P}_{ky}.$$

For $S_k=0$, $k=0$ and $k=n/2$, Eqs. (28) and (29) reduce to the following:

$$\begin{bmatrix} K_{oo} & K_{oa} \cdot (C_k - \bar{T}) \\ \text{Sym} & (C_k - \bar{T})K_{aa} (C_k - \bar{T}) \end{bmatrix} \begin{bmatrix} Q_{oks}^s \\ Q_x \end{bmatrix} = \begin{bmatrix} P_{okc}^a \\ (C_k - \bar{T})P_{akc}^a \end{bmatrix}, \text{ and} \quad (30)$$

$$\begin{bmatrix} K_{oo} & K_{oa} \cdot (C_k + \bar{T}) \\ \text{Sym} & (C_k + \bar{T})K_{aa} (C_k + \bar{T}) \end{bmatrix} \begin{bmatrix} Q_{okc}^s \\ Q_y \end{bmatrix} = \begin{bmatrix} P_{okc}^s \\ (C_k + \bar{T})P_{akc}^s \end{bmatrix}. \quad (31)$$

In the reflective cyclic symmetry procedures, CSR, static solutions are computed as follows:

1. For each value of k ,
 - o The applied loads are factored into their harmonic components according to Eqs.(22).
 - o Eq.(28) (or Eq.(30) if $S_k=0$) is used to compute Q_{oks}^s , Q_{okc}^a , and Q_x .
 - o Eq.(29) (or Eq.(31) if $S_k=0$) is used to compute Q_{okc}^s , Q_{oks}^a , and Q_y .
 - o Eqs.(26) and (27) are used to compute Q_{aks}^s , Q_{akc}^a , Q_{aks}^a , and Q_{akc}^s .
2. Individual sector displacement vectors are computed by successive application of Eqs.(19), (18), and (15).

For a general applied loading, all possible values of k are required for an exact solution. However, provisions are included in CSR for truncating the solution to a specified subset of harmonics.

Eigenvalue problems for cyclically symmetrical structures with reflective symmetry are written as:

$$\lambda \bar{M} U - \bar{K} U = 0 , \quad (32)$$

$$\lambda \bar{KG} U + \bar{K} U = 0 ,$$

The system mass matrix M and geometric stiffness matrix KG have the same form as K in Eq.(13). Performing the transformation of coordinates and imposing the inter-sector compatibility requirements on M and KG as was done with K , results in m uncoupled eigenvalue problems of the following form:

$$\lambda \bar{M}_{kx} \bar{Q}_{kx} - \bar{K}_{kx} \bar{Q}_{kx} = 0 , \quad (33a)$$

For undamped vibration

$$\lambda \bar{M}_{ky} \bar{Q}_{ky} - \bar{K}_{ky} \bar{Q}_{ky} = 0 , \quad (33b)$$

$$\lambda \bar{KG}_{kx} \bar{Q}_{kx} - \bar{K}_{kx} \bar{Q}_{kx} = 0 , \quad (34a)$$

For buckling

$$\lambda \bar{KG}_{ky} \bar{Q}_{ky} - \bar{K}_{ky} \bar{Q}_{ky} = 0 . \quad (34b)$$

\bar{M}_{kx} and \bar{KG}_{kx} have the same form as \bar{K}_{kx} of Eq.(28) or Eq.(30) depending on the value of S_k . \bar{M}_{ky} and \bar{KG}_{ky} have the same form as \bar{K}_{ky} of Eq.(29) or Eq.(31).

The eigenvalues of Eqs.(33a) are identical to the eigenvalues of Eqs.(33b). Eigenvalues of Eqs.(34a) are identical to those of Eqs.(34b). However, solutions to both sets of equations are required for computing complete eigenvectors.

The CSR procedures compute eigenvalue solutions according to Eqs.(33) or (34) for user specified values of k (a through m). Back transformation for the corresponding sector eigenvectors is performed by successive use of Eqs.(20), (27), (19), and (18) to obtain U_i^s and U_i^a . Except for harmonics $k=0$ and $k=n/2$, all system eigenvalues occur in pairs, corresponding to U_i^s and U_i^a , respectively. For $k=0$ and $k=n/2$, the eigenvalues associated with U_i^s and U_i^a are unique.

MACROELEMENT PROCEDURES

by

C. E. Jones

December 1981

EISI

ENGINEERING INFORMATION SYSTEMS, INC

Suite 240 • 5120 Campbell Ave. • San Jose, CA 95130

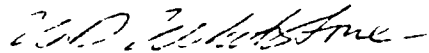
PREFACE

This report was prepared by Engineering Information Systems, Inc., for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration, under contract NAS8-32664. The Contracting Officer's Technical Representative was Mr. L. A. Kiefling.

The macroelement procedures were designed jointly by W. D. Whetstone and C. E. Jones, and were prepared and tested by Dr. Jones.

Submitted by:

Engineering Information Systems, Inc.



W. D. Whetstone
President

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I. INTRODUCTION

The EAL macro element procedures may be used to model structural systems incorporating macro elements. Each macro element is an independent finite element model. Macro elements are commonly used in modeling situations such as the following:

- . Modeling a structure that is made up of a number of identical substructures. In this case, a single macro element model is used to represent all occurrences of a repeated substructure.
- . Modeling specific structural parts such as irregular beams, tapered beams, beams with thin-walled open cross sections, curved beams with non-symmetrical sections, sectors of curved shells, etc. For this type of modeling, the macro element model usually has a finer mesh density than the overall structural model.

Provisions are included in the procedures for back transformation and printing of individual macro element displacements, reactions, and stresses.

The macro element procedures rely heavily on the EAL processors used for substructure analysis. Those processors are AUS/(SSPREP, SSM, SSK), SYN, and SSBT.

In subsequent sections of this report, ME_i is used to denote a macro element name. ME_i is any four character named specified by the user to define a basic macro element.

1.1 TERMINOLOGY

The terminology used in subsequent sections of this report is very similar to the terminology used in Vol. 1 of the EAL Reference Manual in those sections that pertain to substructure analysis.

As illustrated on Figure 1-1, a system consists of system joints interconnected by any number of macro elements and finite elements. Each macro element has one or more boundary nodes, each of which is connected to a system joint. If a boundary node does not coincide with the system joint to which it is connected, the connection is made through a rigid link.

In Figure 1-1, ME_i represents a macro element which is repeated three times. ME_j and ME_k denote macro elements that occur once in the system model.

Each macro element has an associated macro element reference frame, relative to which are defined (1) the locations of the boundary nodes, and (2) the orientation of boundary node reference frames. Each macro element reference frame coincides with one of the system alternate reference frames, each of which is defined by specifying (1) the location of its origin, and (2) the orientation of its axes, relative to the system global frame.

The degrees of freedom that represent the state of the assembled system are the system joint motions. The motion of a system joint is a six component vector relative to a system joint reference frame uniquely associated with the system joint.

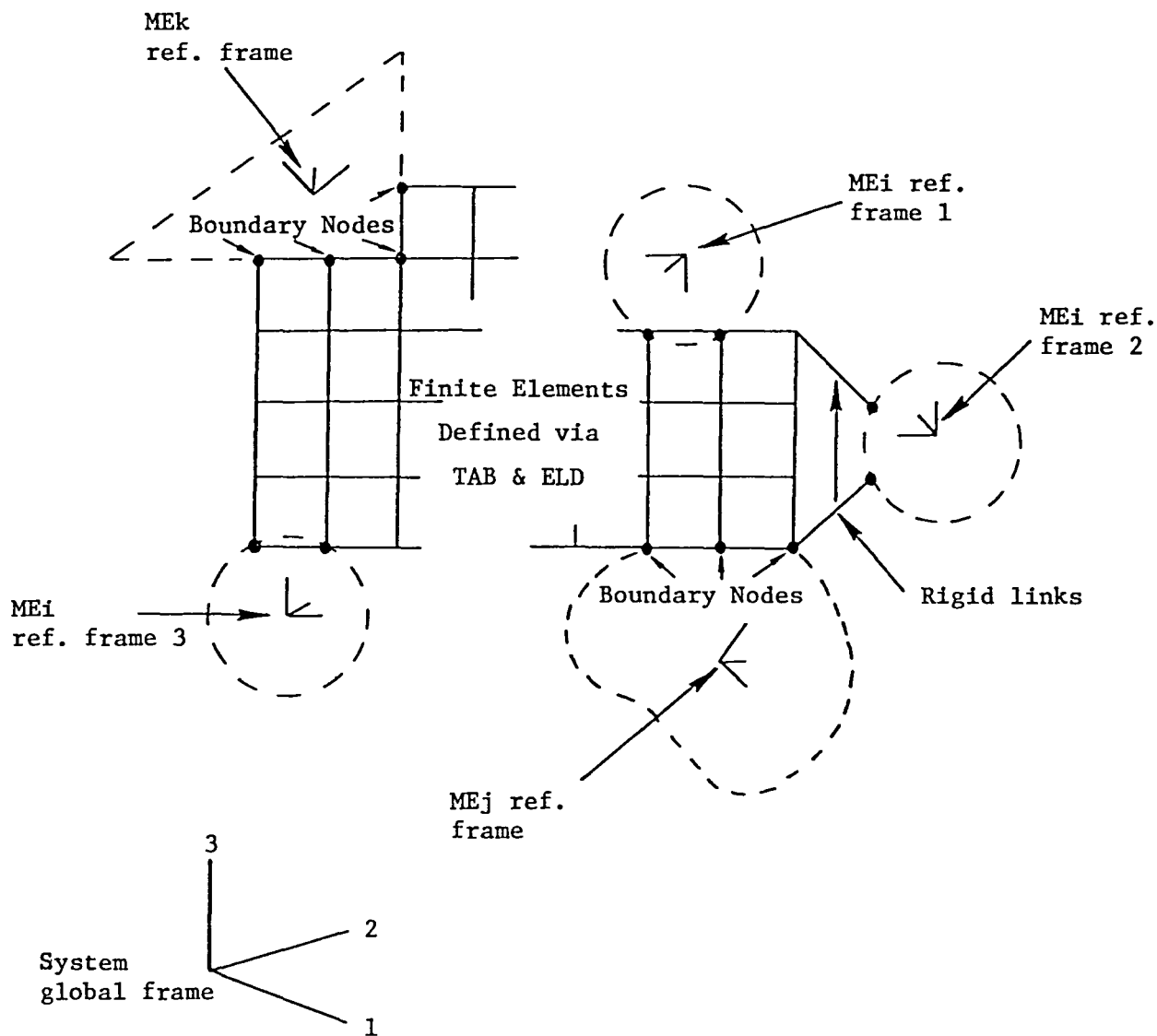


Figure 1-1 Assembled System

1.2 ANALYSIS PROCEDURE

A typical analysis procedure for a macro element assembly is outlined below:

1. Define the finite element model for each unique macro element, as described in Section 2. Each macro element may be repeated any number of times in the system.
2. Define the system, as discussed in Section 2. In addition to macro elements, the system may also contain ordinary finite elements, e.g. E21, E43, ---. It is also permissible for the system to contain only macro elements.
3. Assemble the system mass and stiffness matrices. As produced by the procedure ME SYS, these matrices are named MSYS and KSYS.
4. Perform the system analysis using MSYS and KSYS. The user may compute system vibrational modes, static displacement solutions, dynamic response solutions, etc.
5. As described in Section 3, back transform for the individual macro element displacement vectors associated with the system solution vectors computed in step 4.
6. Print the macro element stresses, reactions, and joint motions as described in Section 4.

Except for step 4, all of the steps are performed automatically by the EAL macro element procedures. Step 4 must be performed by the user.

2. CONSTRUCTING THE ASSEMBLED SYSTEM MASS AND STIFFNESS MATRICES

The primary procedure for constructing system mass and stiffness matrices is ME SYS. Utility procedures that are called by ME SYS are:

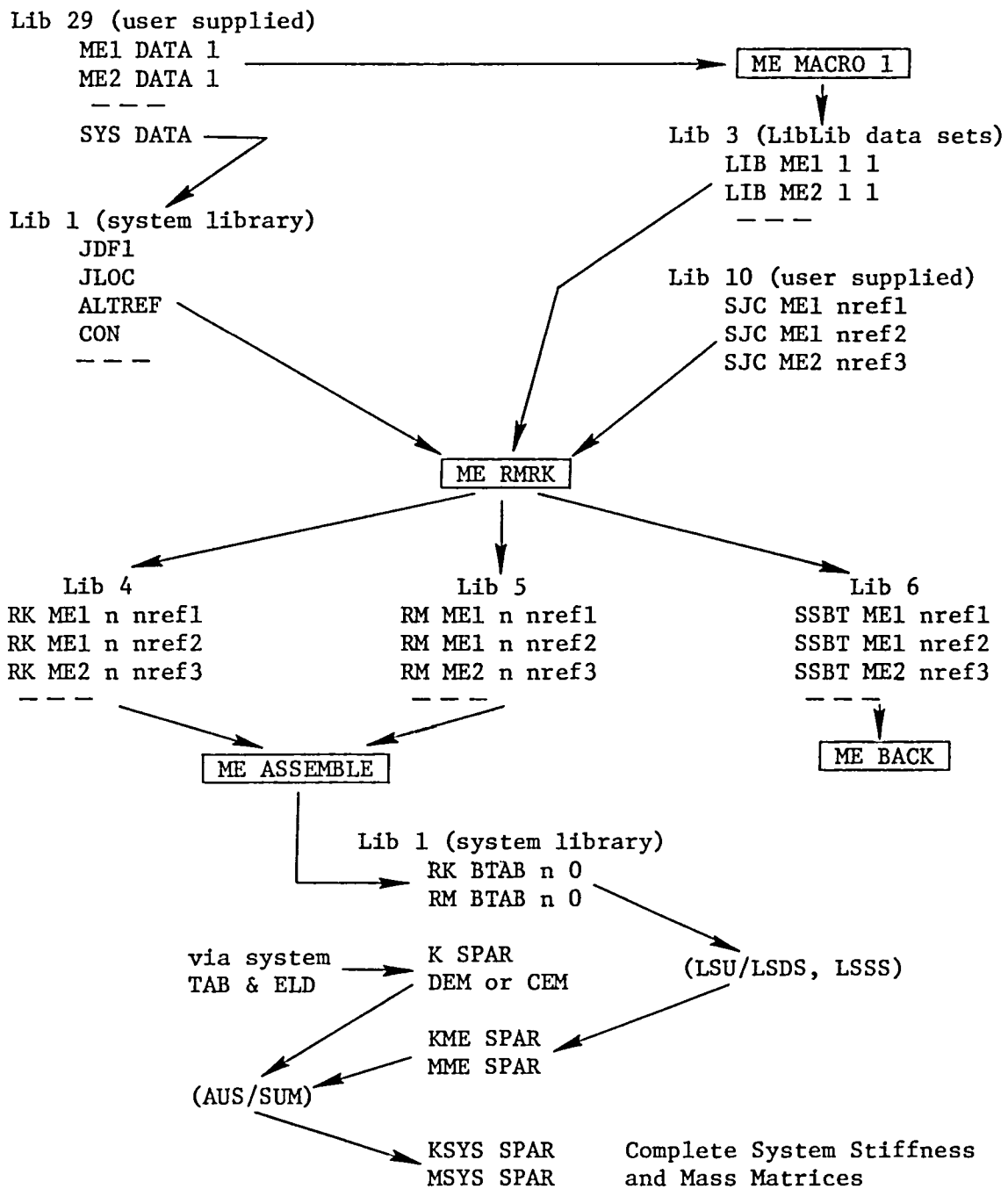
```
ME MACRO 1
ME RMRK, and
ME ASSEMBLE.
```

An information flow diagram for ME SYS is shown on Figure 2-1.

System matrices are constructed by ME SYS in three phases, as follows:

- Phase 1: For each runstream element in library 29 named MEi DATA 1, the procedure ME MACRO 1 computes and stores into library 3 a data set named LIB MEi 1 1. LIB MEi 1 1 is a liblib data set that contains the mass and stiffness matrices for the basic macro element MEi. The stored M and K are computed relative to the macro element reference frame.
- Phase 2: For each runstream element in library 10 named SJC MEi nref, the procedure ME RMRK computes the corresponding contributions to the system mass and stiffness matrices, RM MEi nref and RK MEi nref. These data sets are stored in libraries 4 and 5 in labeled submatrix format. SSBT MEi nref is stored in library 6 for subsequent use in back transformation.
- Phase 3: Using the contents of libraries 4 and 5 and the system finite elements defined via TAB and ELD, the system mass and stiffness matrices, MSYS and KSYS, are computed and stored in library 1.

As discussed in Section 2.1.3, the parameter ASSEM is provided to control the execution of Phase 3. The user may elect not to execute Phase 3 during the model preparation phase of an analysis.



Normal flow of information for constructing the complete system mass and stiffness matrices. This process is carried out by the procedure ME SYS.

Figure 2-1 Information Flow Diagram for ME SYS

2.1.1 INPUT SCHEMATIC, SYSTEM DEFINITION

To construct the system mass and stiffness matrices representing an assemblage of macro elements, proceed as follows:

*XQT U1

```
*(29 ME1 DATA 1)  ENDME1      . Data for macro element ME1
$ ME1 PARAMETER SPECIFICATIONS:
  G=386.,  MNAM = CEM          . Optional parameters; see Sect. 2.1.2.
*(TAB)              . ME1 TAB data
  START jtmel             . 6 DOF per joint
  JLOC
  SA
  ---
*(ELD)              . ME1 ELD data
  Exx
  ---
*(BN)              . ME1 boundary nodes
  j1: j2: j3,j4: ---      . Loop limit format permitted. j1<j2<j3...
*(- --- -)         . Optional Runstream Elements, Sect. 2.1.5.
*                  ENDME1

*(29 ME2 DATA 1)  ENDME2      . Data for macro element ME2
  ---
*                  ENDME2

  ---
  . Data for any number of macro elements

*(SYS DATA)      ENDSYS      . Data for system model
$ SYSTEM PARAMETER SPECIFICATIONS:
  G=386.           . Optional parameters; see Sect. 2.1.3.
*(TAB)
  START jtsys      . 6 DOF per joint
  JLOC             . System joint locations
  ALTREF           . Alternate ref. frames are used to define
                   the position and orientation of macro
                   element ref. frames.
  CON = 1          . System Constraint
  ---
*(ELD)             . Optional system elements defined via ELD
  Exx
  ---
*(- --- -)         . Optional Runstream Elements, Sect. 2.1.5.
*                  ENDSYS
```

*(10 SJC ME1 nref1)
a1: a2: ---

. An ME1 macro element is positioned and oriented according to the system alternate ref. frame nref1. ME1 boundary node j1 is attached to system joint a1; j2 is attached to a2; etc. Loop format is not permitted.

*(10 SJC ME1 nref2)
b1: b2: ---

. Another ME1 macro element is positioned and oriented according to the system alternate ref. frame nref2.

*(10 SJC ME2 nref3)
c1: c2: ---

. An ME2 macro element is positioned and oriented according to the system alternate ref. frame nref3.

. Any number of SJC data sets may be entered into Lib 10.

*CALL (ME SYS)

As illustrated by the flow diagram, Figure 2-1, the procedure ME SYS constructs complete system mass and stiffness matrices named MSYS and KSYS.

For each runstream element in Lib 29 named MEi DATA 1, a Liblib data set is entered into Lib 3 as shown on Figure 2-1. For each SJC MEi nref data set in Lib 10, a data set is entered into Libs 4, 5, and 6, as shown on Figure 2-1.

2.1.2 MEI DATA OPTIONAL PARAMETERS

As shown in Section 2.1.1, optional parameter specifications may be included at the beginning of MEI DATA 1 to change the values of the parameters listed below:

| <u>Parameter Name</u> | <u>Default Value</u> | <u>Meaning</u> |
|---------------------------|--------------------------|---|
| G | 1 | Acceleration of gravity. |
| SEQ | 1 | If nonzero, SEQ is executed for the macro element. |
| MNAME | DEM | Mass matrix name. DEM for diagonal, CEM for consistent. |
| MWARP | .05 | E Reset |
| KFAC | 1 | K Reset |
| SPDP | 2 | K Reset |

Parameter specifications must be the first executable commands in a MEI DATA 1 runstream element.

2.1.3 SYS DATA OPTIONAL PARAMETERS

As shown in Section 2.1.1, optional parameter specifications may be included at the beginning of SYS DATA to change the values of the parameters listed below:

| <u>Parameter Name</u> | <u>Default Value</u> | <u>Meaning</u> |
|---------------------------|--------------------------|---|
| G | 1 | Acceleration of gravity. |
| SEQ | 1 | If nonzero, SEQ is executed for the system. |
| MNAME | DEM | Mass matrix name associated with system ELD elements. DEM for diagonal, CEM for consistent. |
| MWARP | .05 | E Reset } Used only if system elements K Reset } are defined via ELD. K Reset } |
| KFAC | 1 | |
| SPDP | 2 | |
| ASSM | 1 | =1, System matrices, KSYS and MSYS, are assembled during this execution. =0, Macro element matrices are entered into libraries 4, 5, and 6, but the system matrices are not assembled. See the information flow diagram, Figure 2-1. |

Parameter specifications must be the first executable commands in the SYS DATA runstream element.

2.1.4 MASS MATRICES AND RIGID MASSES

To include rigid mass in macro elements or in the system, insert TAB/RMASS input into the appropriate *(TAB) runstream element. See Section 2.1.1. RMASS is automatically added to the corresponding mass matrix (defined by the register MNAME as discussed in Sections 2.1.2 and 2.1.3) to form the total mass, MTOT. MTOT is then used by the macro element procedures as the mass matrix.

2.1.5 OPTIONAL RUNSTREAM ELEMENTS

In the ME procedures, many *XQT commands are followed by optional DCALL commands, such as:

*XQT SEQ
*DCALL, OPT (SEQ OPTIONS)

These optional runstream elements are input as described in Section 2.1.1 for each macro element and for the system. Optional runstream elements that are recognized by the ME procedures are:

| | | |
|--------|----------|-------------------|
| *(E | OPTIONS) | |
| *(EKS | OPTIONS) | |
| *(SEQ | OPTIONS) | |
| *(TAN | OPTIONS) | |
| *(K | OPTIONS) | |
| *(M | OPTIONS) | |
| *(RSI | OPTIONS) | |
| *(SYN | OPTIONS) | See ME RMRK |
| *(LELS | OPTIONS) | See ME RMRK |
| *(SSBT | OPTIONS) | See ME BACK |
| *(LSU | OPTIONS) | For LSDS and LSSS |

Note that calls to other procedures may be initiated through an optional runstream element.

2.2 ADDING OR REPLACING MACRO ELEMENTS IN AN EXISTING MODEL

New macro elements may be added to an existing system model, or macro elements may be replaced in an existing system model by executing the following steps:

1. Attach to the run libraries 1, 3, 4, 5, and 6.
2. Prepare and execute a runstream like the input schematic in Section 2.1.1.

All macro elements processed during the run will cause new data sets to be added to the system libraries, or old data sets to be replaced in the system libraries. Be sure that runstream elements are entered into Libs 29 and 10 only for those macro elements that are to be processed during the execution.

2.3 RIGID CONNECTION BETWEEN SYSTEM JOINTS AND MACRO ELEMENT BOUNDARY NODES

If a macro element boundary node does not geometrically coincide with the system joint to which it is attached, a transformation is performed by the processor SYN that assumes a rigid connection between the two.

3. BACK TRANSFORMATION FROM SYSTEM DISPLACEMENT VECTORS TO INDIVIDUAL MACRO ELEMENT DISPLACEMENT VECTORS

The procedure ME BACK is used to back transform displacement vectors in system SYSVEC format to displacement vectors for the individual macro elements. The macro element displacement vectors are in SYSVEC format in accordance with the characteristics of their respective macro elements.

An information flow diagram for ME BACK is shown on Figure 3-1. Provisions are included for back transformation of static displacement vectors and vibrational modes.

For each runstream element in Lib 10 named SJC MEi nref, ME BACK computes and inserts into Lib 7 a data set named USB MEi nset nref. USB MEi nset nref is the displacement vector for macro element MEi oriented and positioned according to nref.

To execute ME BACK:

1. Attach libraries 1, 3, 6, 7, 10, and "QLIB". The contents of these libraries are shown on Fig. 3-1.
2. *XQT U1
*(BACK PARAMETERS)
 VECT = 'VIBR . Optional Parameters; see the table below.
*CALL (ME BACK)

The optional runstream element BACK PARAMETERS may be used to change the values of the parameters tabulated below:

| <u>Parameter Name</u> | <u>Default Value</u> | <u>Meaning</u> |
|---------------------------|--------------------------|---|
| VECT | 'STAT | = 'STAT For static displacements = 'VIBR For vibrational modes |
| SET | 1 | Set number nset; see Fig. 3-1. |
| CON | 1 | Constraint number ncon; see Fig. 3-1. |
| QLIB | 1 | Solution library; see Fig. 3-1. |

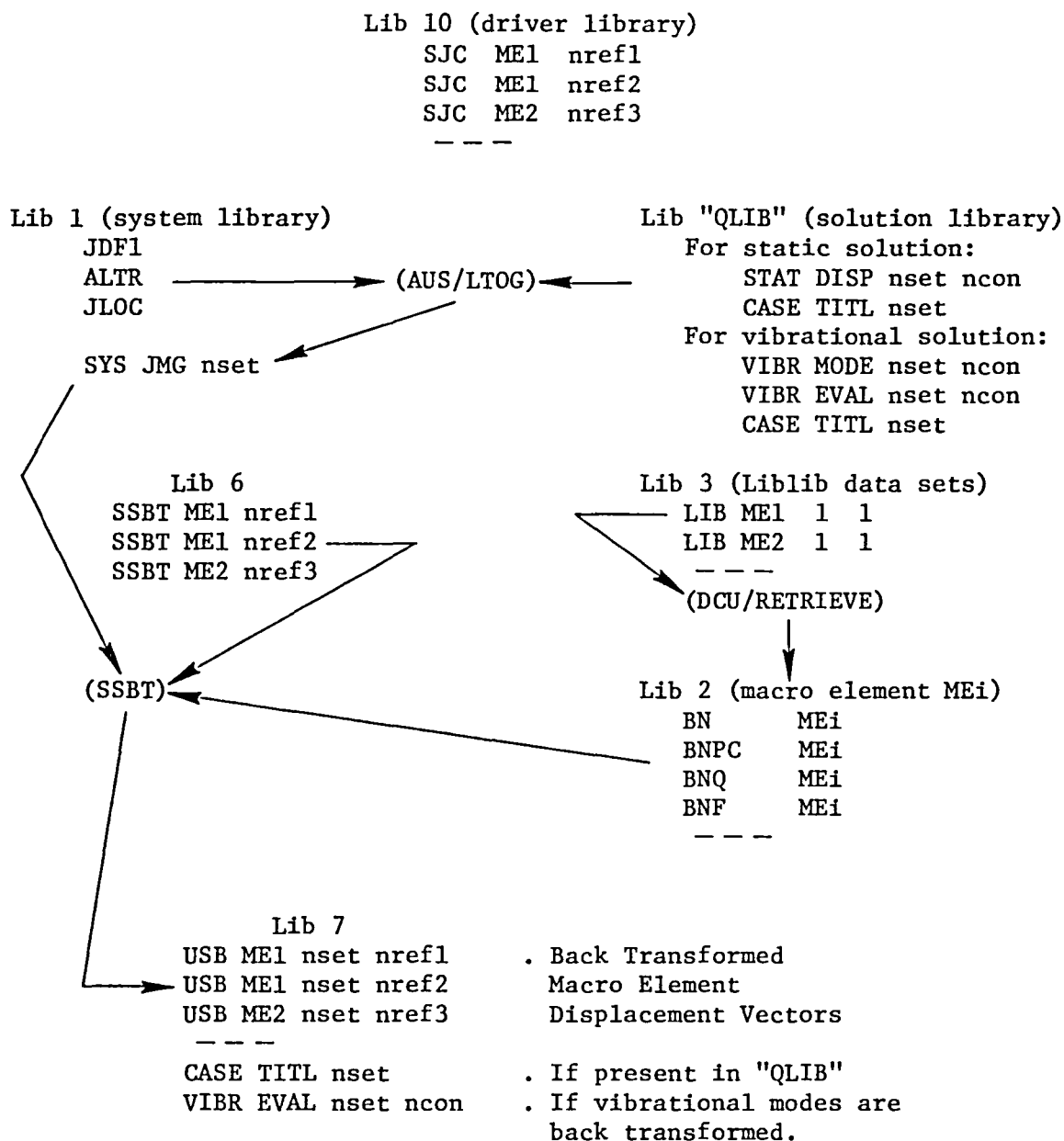


Figure 3-1 Information Flow Diagram for ME BACK

4. PRINTING RESULTS

Procedures are provided for printing stresses, displacements, and reactions for individual macro elements. Stresses are printed using the EAL processor ES. Displacement and reaction vectors are printed using U3/RP2.

For printing stresses, displacements, or reactions, the following EAL libraries must be attached:

- Lib 3. Basic macro element liblib data sets; see Fig. 3-1.
- Lib 7. Back transformed macro element displacement vectors; see Fig. 3-1.
- Lib 10. Driver library containing the SJC MEi nref data sets; see Fig. 3-1.

4.1 STRESS PRINTING

Stresses are printed for each macro element for which a data set named SJC MEi nref resides in Lib 10.

To print macro element stresses:

```
*XQT U1
*(ES PARAMETERS)
    SET = nset    . Default nset = 1
*(ES ALL)
    ES commands that pertain to all macro elements
*(ES MEi)
    ES commands that pertain to all MEi macro elements
*(ES MEi nref)
    ES commands that pertain to the single macro element MEi
    oriented and positioned according to nref.
---
*CALL (ME ES)
```

All of the above input runstream elements are optional.

The runstream elements ES ALL, ES MEi, and ES MEi nref are used to issue any of the ES commands described in Vol. 1 of the EAL Ref. Manual.

To prevent the ES command ALL from being executed, include the register action command !ALL=0 in any of the ES XXXX YYYY runstream elements.

4.2 DISPLACEMENTS AND REACTIONS PRINTING

Displacements or reactions are printed for each macro element for which a data set named SJC MEi nref resides in Lib 10.

To print macro element displacements or reactions:

```
*XQT U1
*(VPRT PARAMETERS)
  SET = nset:  CON = ncon      . Optional parameters; see the
*CALL (ME VPRT)                table below.
```

The optional runstream element VPRT PARAMETERS may be used to change the values of the parameters tabulated below:

| <u>Parameter Name</u> | <u>Default Value</u> | <u>Meaning</u> |
|---------------------------|--------------------------|---|
| SET | 1 | Set number, nset; see Fig. 3-1. |
| CON | 1 | Constraint condition, ncon; see Fig. 3-1. |
| EVAL | 0 | = 0, no eigenvalues displayed. = 'XXXX, eigenvalues in the data set named (XXXX EVAL "SET") are displayed with the appropriate vectors. = 'VIBR, eigenvalues and frequencies in HZ are displayed with the vectors. |
| N1 | 'USB | = 'USB, displacements are printed. = 'REAC, reactions corresponding to the matrix product of the macro element stiffness matrix and USB MEi nset nref are computed and printed. |

The output of ME VPRT is similar to the output of the processor VPRT.

Fixed DOF's are marked with a *. Boundary node DOF's are marked with a B.

5.1 DESCRIPTION OF PROCEDURE FUNCTIONS

ME SYS

This procedure directs construction of the system mass and stiffness matrices by calling the procedures ME MACRO 1, ME RMRK, and ME ASSEMBLE. The total system M and K are named MSYS and KSYS, and are stored in Lib 1.

ME MACRO 1

For each data set in Lib 29 named MEi DATA 1, this procedure stores a Liblib data set in Lib 3 named LIB MEi 1 1. ME MACRO 1 uses the AUS processors SSPREP, SSM, and SSK to compute the data sets BN MEi, BNPC MEi, BNQ MEi, BNF MEi, SSMK MEi 1 1, and SSMK MEi 2 1. These data sets are used by ME RMRK to construct MEi contributions to the system M and K.

ME RMRK

For each data set in Lib 10 named SJC MEi nref, this procedure stores in Lib 4, 5, and 6 data sets named RK MEi n nref, RM MEi n nref, and SSBT MEi nref, respectively. ME RMRK uses the Liblib data set named LIB MEi 1 1 in Lib 3 and the system alternate reference frame nref from Lib 1 to construct the output data sets. RK MEi n nref is that part of the system stiffness matrix associated with the macro element MEi oriented and positioned according to nref and attached through its boundary nodes to the system joints defined in SJC MEi nref. RM MEi n nref is the MEi contribution to the system mass matrix. RK and RM are in labeled submatrix format.

ME ASSEMBLE

This procedure converts the RK MEi n nref data sets in Lib 4 into a single data set named RK BTAB 6 0 in Lib 1. RK BTAB 6 0 is that part of the system stiffness matrix representing the assemblage of all macro elements. The corresponding system mass matrix RM BTAB 6 0 is computed from Lib 5. All data sets involved are in labeled submatrix format.

ME BACK

For each data set in Lib 10 named SJC MEi nref, this procedure stores in Lib 7 a data set named USB MEi nset nref. USB MEi nset nref is the back transformed displacement vector for macro element MEi oriented and positioned according to nref. nset is the set number of the input system displacement vector.

ME ES

For each data set in Lib 10 named SJC MEi nref, this procedure prints element stresses associated with the displacement vector USB MEi nset nref stored in Lib 7.

ME VPRT

For each data set in Lib 10 named SJC MEi nref, this procedure prints in VPRT format the displacement vector USB MEi nset nref stored in Lib 7. ME VPRT optionally prints as reactions the matrix product of the macro element stiffness matrix and USB MEi nset nref.

ME LOOP

This is a utility procedure for looping through all macro elements associated with the data sets in Lib 10 named SJC MEi nref. For each macro element, the following optional calls are made:

```
*DCALL,OPT(LOOP ALL)
*DCALL,OPT(LOOP "SSID")
*DCALL,OPT(LOOP "SSID" "NREF"),
```

where "SSID" and "NRFF" take on all values of MEi and nref.

5.2 PROCEDURE LISTINGS

The following pages are U1/PRT listings of the macro element procedures listed below:

| | | | | |
|----|----|----------|---|---|
| 1. | ME | SYS | 0 | 0 |
| 2. | ME | MACRO | 1 | 0 |
| 3. | ME | RMRK | 0 | 0 |
| 4. | ME | ASSEMBLE | 0 | 0 |
| 5. | ME | BACK | 0 | 0 |
| 6. | ME | ES | 0 | 0 |
| 7. | ME | VPRT | 0 | 0 |
| 8. | ME | LOOP | 0 | 0 |

ME SYS 0 0

CREATED: 811210 123433
PRINTED: 811210 123700

```
1 $
2 $ THIS PROCEDURE DIRECTS THE CONSTRUCTION OF SYSTEM MASS AND
3 $ STIFFNESS MATRICES FOR ASSEMBLAGES OF MACRO ELEMENTS PLUS
4 $ ELEMENTS DEFINED VIA TAB AND ELD.
5 $
6 $ FORM THE BASIC MACRO ELEMENT LIBLIB DATA SETS:
7 *LIBS 2 1 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
8 *CALL(ME MACRO 1)
9 *LIBS 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
10 $
11 $ INPUT THE SYSTEM TAB AND ELD DATA:
12 *XQT U1
13     !OPT=0
14 *DLIB=20
15 $
16 $ DEFAULT REGISTERS:
17 *RGI
18     SEQ=      1$ =1, SEQ IS EXECUTED FOR THE SYSTEM
19 $              =0, SEQ IS NOT EXECUTED FOR THE SYSTEM
20     ASSM=     1$ =1, SYSTEM MATRICES ARE ASSEMBLED THIS EXECUTION
21 $              =0, MACRO ELEMENT MATRICES ARE FORMED, BUT SYSTEM
22 $              MATRICES ARE NOT ASSEMBLED.
23     G=        1.$ ACCELERATION OF GRAVITY
24     MNAM=     DEM
25     MWARP=    .05$ E RESET
26     KFAC=     1$ K RESET
27     SPDP=     2$ K RESET
28 *DCALL,OPT(29 SYS DATA)
29     !TAB=TOC,IERR(20 TAB MASK MASK MASK)
30 *                                           JNZ(TAB,800)
31 *XQT TAB
32 *DCALL(TAB)
33 *                                           LABEL 800
34     !ELD=TOC,IERR(20 ELD MASK MASK MASK)
35 *                                           JNZ(ELD,100)
36 *XQT ELD
37 *DCALL(ELD)
38 *                                           LABEL 100
39 $
40 $ COMPUTE MACRO ELEMENT M AND K MATRICES:
41 *CALL(ME RMRK)
42 $
43 *                                           JZ( ASSM,200)
44 $ ASSEMBLE THE MACRO ELEMENT RM AND RK:
45 $
46 *CALL(ME ASSEMBLE)
47 $
48 $ ASSEMBLE THE M AND K DEFINED VIA TAB AND ELD:
49     !ELD=TOC,IERR(1 ELTS NAME 0 0)
50 *                                           JNZ(ELD,300)
```

ME SYS 0 0

CREATED: 811210 123433
PRINTED: 811210 123700

```
51      !TNAM='DEM
52      !TEST=EQUAL(MNAM,TNAM): !CEM=0
53      *                                     JNZ(TEST,1000)
54      !CEM=1$ CONSISTENT MASS MATRIX
55      *                                     LABEL 1000
56      *CALL(SPREP)
57      *                                     JUMP 400
58      *                                     LABEL 300
59      *                                     JZ(SEQ,500)
60      *XQT SEQ
61      *DCALL,OPT(SEQ OPTIONS)
62      *                                     LABEL 500
63      *XQT TAN
64      *DCALL,OPT(TAN OPTIONS)
65      *                                     LABEL 400
66      $ REFORMAT THE MACRO ELEMENT M AND K:
67      $
68      *XQT LSU
69      *DCALL,OPT(LSU OPTIONS)
70      !SPD1=SPDP-1: !LS='LSSS
71      *                                     JZ(SPD1,600)
72      !LS='LSDS
73      *                                     LABEL 600
74      KME="LS"(RK): MME=LSSS(RM)
75      *                                     JZ(ELD,700)
76      $ NO ELD ELEMENTS:
77      $
78      *XQT DCU
79      TOCCHG 1 KME SPAR MASK MASK: N1=KSYS
80      TOCCHG 1 MME SPAR MASK MASK: N1=MSYS
81      *                                     JUMP 900
82      *                                     LABEL 700
83      $ ELD ELEMENTS INCLUDED:
84      $
85      *XQT AUS
86      KSYS=SUM(K,KME): MSYS=SUM("MNAM",MME)
87      *                                     LABEL 900
88      *                                     LABEL 200
89      *                                     RETURN
```

ME MACR 1 0

CREATED: 811210 123433
PRINTED: 811210 123700

```
1  $
2  $ THIS PROCEDURE FORMS THE BASIC LIBLIB LIBRARY FOR MACRO ELEMENTS
3  $ DEFINED VIA (SSID DATA 1) DATA SETS IN LIB 29.
4  $
5  *XQT U1
6  *REGISTER EXCEPTIONS
7  *REGISTER STORE(29 REGI HOUSE 1 1)
8  *DLIB=20
9      !ISEQ=0: !SYS='SYS
10  * LABEL 1000
11      !SSID=TOC,N1(29 MASK DATA 1 MASK),ISEQ
12  * JLZ(ISEQ,2000)
13      !TEST=EQUAL(SSID,SYS)$ =0, FOR NO EQUALITY
14  * JNZ(TEST,1000)
15  *XQTC U1
16  *FREE 20
17  *FREE 1
18      !OPT=0
19  $
20  $ DEFAULT REGISTERS:
21  *RGI
22      G= 1.$ ACCELERATION OF GRAVITY
23      SEQ= 1$ NON-ZERO VALUE SEQ IS EXECUTED FRO "SSID"
24      MNAM= DEM
25      MWARP= .05$ E RESET
26      KFAC= 1$ K RESET
27      SPD= 2$ K RESET
28  *DCALL(29 "SSID" DATA 1)
29  $
30      !BLANK='
31      !TNAM='DEM
32      !TEST=EQUAL(MNAM,TNAM): !CEM=0
33  * JNZ(TEST,100)
34      !CEM=1$ CONSISTENT MASS MATRIX
35  * LABEL 100
36  *XQT AUS
37      TABLE(NI=1,NJ=1): "SSID" ME
38  *XQT TAB
39  *DCALL(TAB)
40      UPDATE=1: CON=1: NONZERO 1 2 3 4 5 6
41  *DCALL(BN)
42      DC FLAG CON "BLANK",*,B
43  *XQT ELD
44  *DCALL(ELD)
45  $
46  $ FORM THE MACRO ELEMENT K AND M MATRICES:
47  *CALL(SPREP)
48      !CONR=1: !KNAM='K
49  *CALL(FACTOR)
50  *XQT AUS
```

ME MACR 1 0

CREATED: 811210 123433
PRINTED: 811210 123700

```
51    *DCALL,OPT(AUS OPTIONS)
52       SSID="SSID": SSPREP("KNAM", "CONR")
53       SSK("KNAM"): SSM("MNAM")
54    *XQT DCU
55       LIBLIB=3: STORE 1 LIB "SSID" 1 1
56    *
57    *
58    *XQTC U1
59    *DLIB=29
60    *REGISTER RETRIEVE(29 REGI HOUSE 1 1)
61    *FREE 1
62    *FREE 20
63    *
JUMP 1000
LABEL 2000
RETURN
```

ME RMRK 0 0

CREATED: 811201 190309
PRINTED: 811201 190341

```
1  $
2  $ THIS PROCEDURE IS DRIVEN BY THE DATA SETS RESIDING IN LIBRARY 10.
3  $ MACRO ELEMENT LABELED SUBMATRIX M AND K MATRICES ARE ENTERED INTO
4  $ LIBS 4 AND 5, RESPECTIVELY, FOR EACH MACRO ELEMENT PROCESSED.
5  $
6  *XQTC U1
7  *REGISTER EXCEPTIONS
8  *REGISTER STORE( 29 REGI HOUSE 1 1)
9  $
10 $ SET UP CONSTRAINT 9999 IN LIB 1.  CON 9999 HAS ALL SYSTEM
11 $ DOF'S UNCONSTRAINED.
12 $
13     !TEST=TOC,IERR(1 CON MASK 9999 0)
14 *                                           JZ(TEST,200)
15 *XQT TAB
16     CON 9999
17 *                                           LABEL 200
18     !ISEQ=0: !MEOL=0: !OPT=0
19 *                                           LABEL 1000
20     !SSID=TOC,N2(10 SJC MASK MASK MASK),ISEQ: !JSEQ=ISEQ-1
21 *                                           JLZ(ISEQ,END)
22     !TEST=EQUAL(SSID,MEOL)$  =0 FOR NO EQUALITY
23 *                                           JNZ(TEST,100)
24 $ NEW MACRO ELEMENT SSID:
25 $
26 *XQTC DCU
27     LIBLIB=3: RETR 2 LIB "SSID" 1 1
28     !MEOL=SSID: !NBN=TOC,NI(2 BN "SSID" MASK MASK)
29 *                                           LABEL 100
30     !NREF=TOC,N3(10 SJC "SSID" MASK MASK),JSEQ
31 $ MACRO ELEMENT DEFINED BY SSID AND NREF:
32 $
33 *XQT SYN
34 *FREE 8
35     RESET LIBC=8,LIBB=0,LIBA=6,CON=9999
36 *DCALL,OPT(SYN OPTIONS)
37     "SSID" 2 "NREF"
38 *DCALL(10 SJC "SSID" "NREF" MASK)
39 *XQT LSU
40 *DCALL,OPT(LELS OPTIONS)
41     4 RK "SSID" MASK "NREF"= LELS(8 SYN K 10000)
42     5 RM "SSID" MASK "NREF"= LELS(8 SYN M 10000)
43 *                                           JUMP 1000
44 *                                           LABEL END
45 *XQT U1
46 *REGISTER RETRIEVE(29 REGI HOUSE 1 1)
47 *                                           RETURN
```

ME ASSE 0 0

CREATED: 811201 190309
PRINTED: 811201 190341

```
1  $
2  $ THIS PROCEDURE COMBINES RK AND RM DATA SETS IN LIBS 4 AND 5 INTO
3  $ SINGLE RK AND RM DATA SETS IN LIB 1.
4  $
5  *XQTC U1
6  *REGISTER EXCEPTIONS
7  *REGISTER STORE(29 REGI HOUSE 1 1)
8      !NDO=2: !LIB=4: !RMRK='RK
9      !SECT=28$$$ FUTURE REGISTER ACTION COMMAND $$$
10 *XQT AUS
11     TABLE(NI=1,NJ=1): 4 END END 999 999: J=1: 1.
12     TABLE(NI=1,NJ=1): 5 END END 999 999: J=1: 1.
13 *XQT DCU
14 *
15 *FREE 8
16     COPY "LIB",8
17     !ISEQ=0
18     !RR1=TOC,RR(8 "RMRK" MASK MASK MASK),ISEQ
19     !RR=TOC,RR(8 END END 999 999): !NWDS=RR-RR1*SECT
20     !NJ= TOC,NJ( "LIB" "RMRK" MASK MASK MASK)
21     !N3= TOC,N3( "LIB" "RMRK" MASK MASK MASK)
22     !NINJ=TOC,NINJ("LIB" "RMRK" MASK MASK MASK)
23     !NSEC=NINJ/SECT: !NSEC=NSEC*SECT: !NTST=NSEC-NINJ
24 *
25     !NSEC=NSEC+SECT
26 *
27     !NWDS=NWDS/NSEC: !NWDS=NWDS*NINJ
28     REPOS 8,"RR1"
29     XLOAD 8,1 "NWDS" "NJ" "NINJ" -1 "RMRK" BTAB "N3" 0
30     !LIB=5: !RMRK='RM
31 *
32 *XQT U1
33 *REGISTER RETRIEVE(29 REGI HOUSE 1 1)
34 *
35     LABEL 1000
36     JZ(NTST,200)
37     LABEL 200
38     JGZ,-1(NDO,1000)
39     RETURN
```

```

1  $
2  $ THIS PROCEDURE BACK TRANSFORMS FROM SYSTEM DISPLACEMENT
3  $ VECTORS (SYSVEC FORMAT) TO MACRO ELEMENT DISPLACEMENT
4  $ VECTORS.  EACH MACRO ELEMENT FOR WHICH A DATA SET NAMED
5  $ (SJC "SSID" "NREF") RESIDES IN LIB 10 IS PROCESSED.
6  $
7  *XQTC U1
8  *REGISTER EXCEPTIONS
9  *REGISTER STORE(29 REGI HOUSE 1 1)
10 $
11 $ DEFAULT REGISTERS:
12     !OPT=0
13 *RGI
14     VECT=    STAT  $ FOR STATIC DISPLACEMENTS
15 $         =    VIBR  $ FOR VIBRATIONAL MODES
16 $         =    BUCK  $ FOR BUCKLING MODES
17     SET=      1  $ SET NUMBER
18     CON=      1  $ CONSTRAINT CONDITION
19     QLIB=     1  $ DISPLACEMENT VECTOR LIBRARY
20 *DCALL,OPT(BACK PARAMETERS)$ OPTIONAL REGISTERS
21     !STAT='STAT
22     !N2='DISP
23     !VTST=EQUAL(VECT,STAT)$ =0 FOR NO EQUALITY
24     !ISEQ=0
25 *                                     LABEL 400
26     !IERR=TOC,IERR(1 SYS JMG MASK MASK),ISEQ
27 *                                     JLZ(ISEQ,300)
28 *XQTC DCU
29     DISABLE 1 "ISEQ"
30 *                                     JUMP 400
31 *                                     LABEL 300
32 *XQTC DCU
33     !IERR=TOC,IERR("QLIB" CASE TITL "SET" MASK)
34 *                                     JNZ(IERR,500)
35     COPY "QLIB",7 CASE TITL "SET"
36 *                                     LABEL 500
37 *                                     JNZ(VTST,600)
38     COPY "QLIB",7 "VECT" EVAL "SET" "CON": !N2='MODE
39 *                                     LABEL 600
40 $
41 $ TRANSFORM TO SYSTEM GLOBAL COORDINATES:
42 *XQT AUS
43     DEFINE U= "QLIB" "VECT" "N2" "SET" "CON"
44     SYS JMG "SET" "CON"= LTOG(U)
45     !ISEQ=0: !MEOL=0
46 *                                     LABEL 1000
47     !SSID=TOC,N2(10 SJC MASK MASK MASK),ISEQ: !JSEQ=ISEQ-1
48 *                                     JLZ(ISEQ,END)
49     !TEST=EQUAL(SSID,MEOL)$ =0 FOR NO EQUALITY
50 *                                     JNZ(TEST,100)

```


ME BACK 0 0

CREATED: 811210 123433
PRINTED: 811210 123700

```
51 $ NEW MACRO ELEMENT SSID:
52 $
53 *XQT DCU
54 LIBLIB=3: RETR 2 LIB "SSID" 1 1
55 !MEOL=SSID
56 *XQT SSBT
57 RESET JMG=0
58 *DCALL,OPT(SSBT OPTIONS)
59 * LABEL 100
60 !NREF=TOC,N3(10 SJC "SSID" MASK MASK),JSEQ
61 $ MACRO ELEMENT DEFINED VIA SSID AND NREF:
62 $
63 "SSID" 2 7 "NREF" 6
64 * JUMP 1000
65 * LABEL END
66 *XQT U1
67 *REGISTER RETRIEVE(29 REGI HOUSE 1 1)
68 * RETURN
```

ME ES 0 0

CREATED: 811210 123433

PRINTED: 811210 123700

```
1 $
2 $ THIS PROCEDURE EXECUTES ES FOR EACH SJC DATA SET IN LIB 10.
3 $ HEADINGS ARE PRODUCED WITH THE ES PRINTOUT TO IDENTIFY THE
4 $ MACRO ELEMENT AND THE ASSOCIATED REFERENCE FRAME.
5 $
6 *XQT U1
7 *REGISTER EXCEPTIONS
8 *REGISTER STORE(29 REGI HOUSE 1 1)
9 $
10 $ DEFAULT REGISTERS:
11     !OPT=0
12 *RGI
13     SET= 1$ SET NUMBER
14 *DCALL,OPT(ES PARAMETERS)$ OPTIONAL REGISTERS
15 *LIBS 2 1 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
16     !ISEQ=0: !MEOL=0: !OPT=0
17 *                                     LABEL 1000
18     !SSID=TOC,N2(10 SJC MASK MASK MASK),ISEQ: !JSEQ=ISEQ-1
19 *                                     JLZ(ISEQ,END)
20     !TEST=EQUAL(SSID,MEOL)$ =0 FOR NO EQUALITY
21 *                                     JNZ(TEST,100)
22 $ NEW MACRO ELEMENT SSID:
23 $
24 *XQT DCU
25     LIBLIB=3: RETRIEVE 1 LIB "SSID" 1 1
26     !MEOL=SSID
27 *                                     LABEL 100
28     !NREF=TOC,N3(10 SJC "SSID" MASK MASK),JSEQ
29 $ MARCO ELEMENT DEFINED VIA SSID AND NREF:
30 $
31     !TEST=TOC,IERR(7 HEAD "SSID" "NREF" 0)
32 *                                     JZ(TEST,200)
33 *XQT U3
34     RP2
35     OUTP=7 HEAD "SSID" "NREF" 0
36     FORMAT 1'(37HPAGE 0'STRESS DATA FOR MACRO ELEMENT ,A4,7H, NREF=I3)
37     PRINT(1) "SSID" "NREF"
38 *                                     LABEL 200
39 *XQTC ES
40     !ALL=1
41     U=7 USB "SSID" "SET" "NREF"
42 *DCALL,OPT(7 HEAD "SSID" "NREF" 0)
43 *DCALL,OPT(ES ALL)
44 *DCALL,OPT(ES "SSID")
45 *DCALL,OPT(ES "SSID" "NREF")
46 *                                     JZ(ALL,300)
47     ALL
48 *                                     LABEL 300
49 *                                     JUMP 1000
50 *                                     LABEL END
51 *XQT U1
52 *REGISTER RETRIEVE(29 REGI HOUSE 1 1)
53 *LIBS 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
54 *                                     RETURN
```

ME VPRT 0 0

CREATED: 811210 123433
PRINTED: 811210 123700

```
1 $
2 $ THIS PROCEDURE SIMULATES VPRT PRINTOUT FOR EACH MACRO ELEMENT
3 $ FOR WHICH A DATA SET NAMED (SJC "SSID" "NREF") RESIDES IN
4 $ LIB 10.
5 $
6 *XQT U1
7 *REGISTER EXCEPTIONS
8 *REGISTER STORE(29 REGI HOUSE 1 1)
9 *LIBS 2 1 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
10 $
11 $ DEFAULT REGISTERS:
12 $ !OPT=0
13 *RGI
14 SET= 1 $ SET NUMBER
15 CON= 1 $ CONSTRAINT CONDITION
16 EVAL= 0 $ NO EIGENVALUES ARE DISPLAYED
17 $ = VIBR $ EIGENVALUES IN THE DATA SET (VIBR EVAL) ARE
18 $ DISPLAYED WITH THE APPROPRIATE VECTORS.
19 $ = BUCK $ EIGENVALUES IN THE DATA SET (BUCK EVAL) ARE
20 $ DISPLAYED WITH THE APPROPRIATE VECTORS.
21 N1= USB $ DISPLACEMENTS ARE PRINTED
22 $ = REAC $ REACTIONS CORRESPONDING TO THE MATRIX PRODUCT
23 $ OF K AND USB ARE COMPUTED AND PRINTED.
24 *DCALL,OPT(VPRT PARAMETERS)
25 !REAC='REAC
26 !BLANK='
27 !VIBR='VIBR
28 !CASE=TOC,IERR(7 CASE TITLE "SET" MASK)
29 !RTST=EQUAL(N1,REAC): !ETST=EQUAL(EVAL,VIBR)$ =0 FOR NO EQUALITY
30 * JZ(EVAL,130)
31 * JZ(ETST,130)
32 *XQTC AUS
33 DEFINE E=7 "EVAL" EVAL "SET"
34 7 "EVAL" HZ "SET"= SQRT(.0253303 E)
35 * LABEL 130
36 !IFMT=1: !ISEQ=0: !MEOL=0
37 * JZ(RTST,1000)
38 !IFMT=2
39 * LABEL 1000
40 !SSID=TOC,N2(10 SJC MASK MASK MASK),ISEQ: !JSEQ=ISEQ-1
41 * JLZ(ISEQ,END)
42 !TEST=EQUAL(SSID,MEOL)$ =0 FOR NO EQUALITY
43 * JNZ(TEST,100)
44 $
45 $ NEW MACRO ELEMENT SSID:
46 *XQT DCU
47 LIBLIB=3: RETRIEVE 1 LIB "SSID" 1 1: !MEOL=SSID
48 !IERR=TOC,IERR(1 FLAG CON "CON" 0)
49 * JZ(IERR,100)
50 *XQT TAB
```

ME VPRT 0 0

CREATED: 811210 123433
PRINTED: 811210 123700

```

51  UPDATE=1: CON="CON": DC FLAG CON "BLANK",*,B
52  * LABEL 100
53      !NREF=TOC,N3(10 SJC "SSID" MASK MASK),JSEQ
54  * JZ(RTST,200)
55      !IERR=TOC,IERR(7 REAC "SSID" "SET" "NREF")
56  * JZ(IERR,200)
57  *XQT AUS
58      DEFINE X=7 USB "SSID" "SET" "NREF"
59      7 REAC "SSID" "SET" "NREF"= PROD(K,X)
60  * LABEL 200
61  *XQTC U3
62      RP2
63      !NLH=4
64  * JZ(EVAL,500)
65      !NLH=NLH+1
66  * LABEL 500
67  * JNZ(CASE,600)
68      !NLH=NLH+1
69  * LABEL 600
70  NUMBER OF FORMATS=8
71  FORMAT 1'(29H 1DISPLACEMENTS, MACRO ELEMENT 1XA4, 7H, NREF= I4)
72  FORMAT 2'(25H 1REACTIONS, MACRO ELEMENT 1XA4, 7H, NREF= I4)
73  FORMAT 3'(5H SET=I4,6H, CON=I4,9H, VECTOR=I4)
74  FORMAT 4'(1X,19A4)
75  FORMAT 5'(12H EIGENVALUE= E14.7, 9H, FREQ= F12.4, 3H HZ)
76  FORMAT 6'(12H EIGENVALUE= E14.7)
77  FORMAT 7'(/6H JOINT,7X1H1,10X1H2,10X1H3,10X1H4,10X1H5,10X1H6)
78  FORMAT 8'(I6,6(E10.3,A1))
79      !NVEC=TOC,NBLOCKS(7 "N1" "SSID" "SET" "NREF"): !IVEC=1
80  DEFINE F=1 FLAG CON "CON"
81  * LABEL 300
82  DEFINE X=7 "N1" "SSID" "SET" "NREF" "IVEC"
83  * JNZ(CASE,400)
84  DEFINE C=7 CASE TITLE "SET" MASK "IVEC"
85  * LABEL 400
86  * JZ(EVAL,210)
87      !E=DS,"IVEC",1,1(7 "EVAL" EVAL "SET" MASK)
88  * JZ(ETST,210)
89      !HZ=DS,"IVEC",1,1(7 "EVAL" HZ "SET" MASK)
90  * LABEL 210
91  NLH="NLH": NLH 1="NLH"
92  LAYOUT
93      WRITE(ALL,"IFMT") "SSID", "NREF"
94      WRITE(ALL,3) "SET","CON","IVEC"
95  * JZ(EVAL,110)
96  * JZ(ETST,120)
97      WRITE(ALL,5) "E","HZ"
98  * JUMP 110
99  * LABEL 120
100     WRITE(ALL,6) "E"

```

ME VPRT 0 0

CREATED: 811210 123433
PRINTED: 811210 123700

```
101 * LABEL 110
102 * JNZ(CASE,130)
103 WRITE(ALL,4) C
104 * LABEL 130
105 WRITE(ALL,7)
106 WRITE(MAIN,8) J,X(1),F(1),X(2),F(2),X(3),F(3),X(4),F(4),>
107 X(5),F(5),X(6),F(6)
108 PRODUCE REPORT
109 !IVEC=IVEC+1
110 * JGZ,-1(NVEC,300)
111 * JUMP 1000
112 * LABEL END
113 *XQT U1
114 *REGISTER RETRIEVE(29 REGI HOUSE 1 1)
115 *LIBS 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
116 * RETURN
```

ME LOOP 0 0

CREATED: 811201 190309
PRINTED: 811201 190341

```
1  $
2  $ THIS IS A MACRO ELEMENT UTILITY PROCEDURE.  THE FOLLOWING
3  $ OPTIONAL CALLS ARE MADE FOR EACH MACRO ELEMENT FOR WHICH A
4  $ DATA SET NAMED (SJC "SSID" "NREF") RESIDES IN LIB 10:
5  $      *DCALL,OPT(LOOP ALL)
6  $      *DCALL,OPT(LOOP "SSID")
7  $      *DCALL,OPT(LOOP "SSID" "NREF")
8  $ WHERE "SSID" AND "NREF" TAKE ON ALL VALUES AS DICTATED BY
9  $ BY THE CONTENTS OF LIB 10.  AT THE TIME OF THE OPTIONAL CALL
10 $ LIB 2 IS THE MAIN "SSID" LIBRARY.
11 $
12 *XQT U1
13 *REGISTER EXCEPTIONS
14 *REGISTER STORE(29 REGI HOUSE 1 1)
15     !ISEQ=0: !MEOL=0: !OPT=0
16 *
17     !SSID=TOC,N2(10 SJC MASK MASK MASK),ISEQ: !JSEQ=ISEQ-1
18 *
19     !TEST=EQUAL(SSID,MEOL)$ =0 FOR NO EQUALITY
20 *
21 $ NEW MACRO ELEMENT SSID:
22 $
23 *XQT DCU
24     LIBLIB=3: RETRIEVE 2 LIB "SSID" 1 1
25     !MEOL=SSID
26 *
27     !NREF=TOC,N3(10 SJC "SSID" MASK MASK),JSEQ
28 $
29 $ MARCO ELEMENT DEFINED VIA SSID AND NREF:
30 $
31 *DCALL,OPT(LOOP ALL)
32 *DCALL,OPT(LOOP "SSID")
33 *DCALL,OPT(LOOP "SSID" "NREF")
34 *
35 *
36 *XQT U1
37 *REGISTER RETRIEVE(29 REGI HOUSE 1 1)
38 *
```

LABEL 1000
JLZ(ISEQ,END)
JNZ(TEST,100)

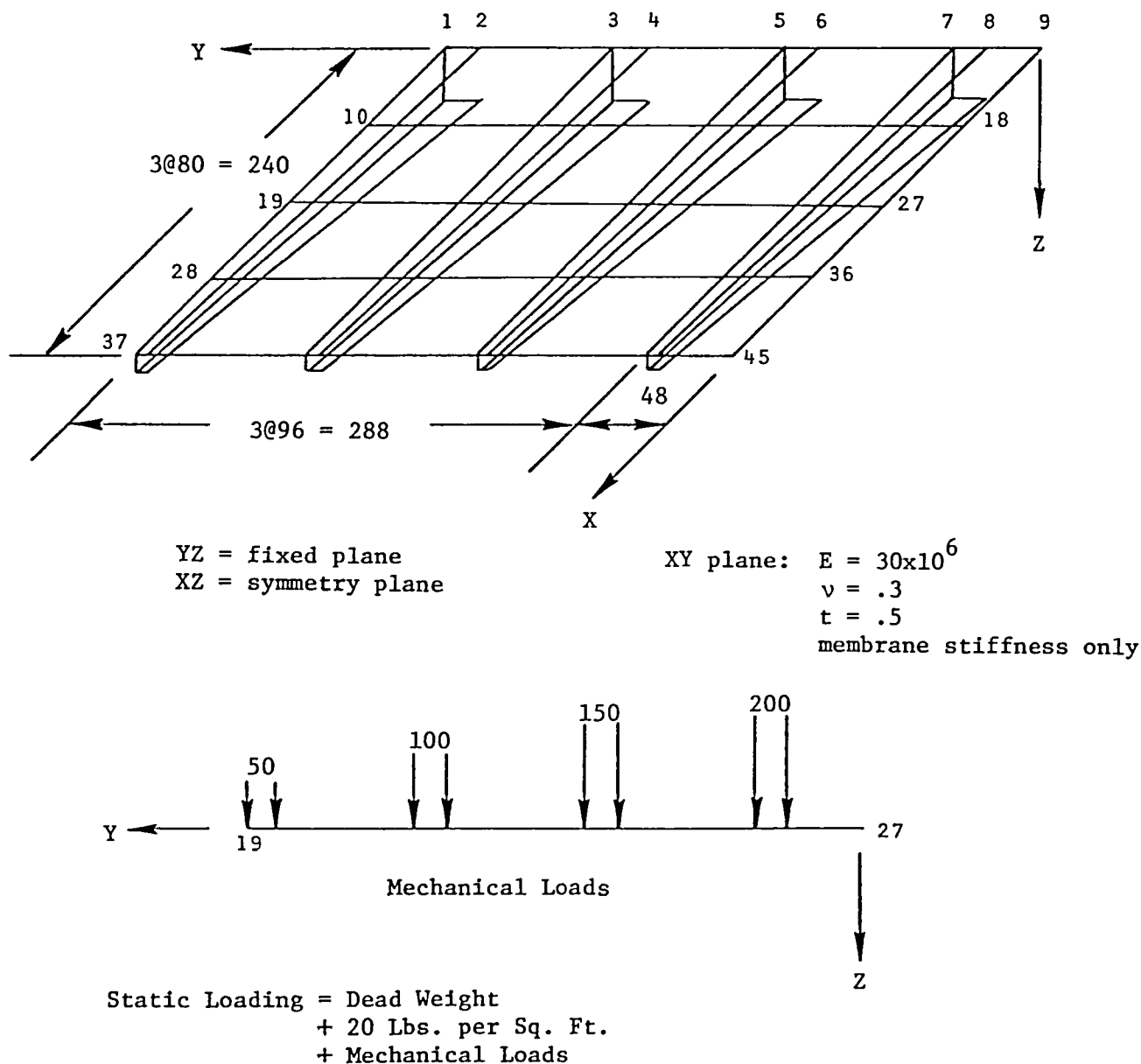
LABEL 100

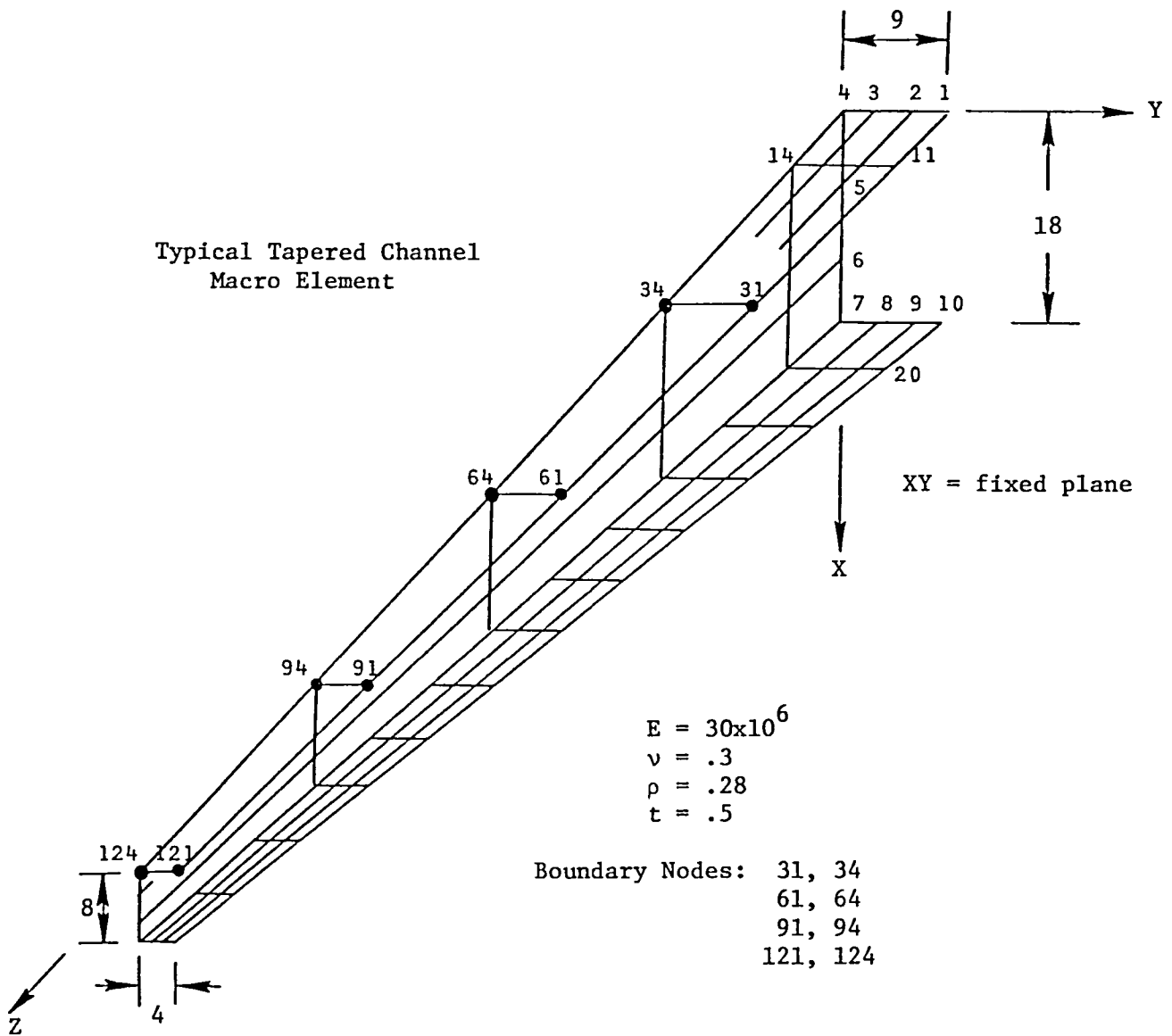
JUMP 1000
LABEL END

RETURN

6.1 STATIC DISPLACEMENTS OF A FLAT ROOF SUPPORTED BY TAPERED CHANNELS

The EAL macro element procedures were used to compute the static solution for the system model described below. All tapered channels are identical and are represented by the single macro element model shown on page 6.1-2. The system model consists of the membrane finite elements lying in the XY plane plus four repeated macro elements representing the tapered channels. The input runstream for the problem is shown on pages 6.1-3 and 6.1-4. Sample printout of the computed results are shown on pages 6.1-5 through 6.1-9. Tables of contents for all pertinent EAL libraries are shown on pages 6.1-10 through 6.1-12.






```

1  *XQT U1
2  $ DEFINE THE TAPERED CHANNEL MACRO ELEMENT:
3  *(CHNL DATA 1)                                END
4  $ MACRO ELEMENT PARAMETERS:
5      G=386.$ ACCELERATION OF GRAVITY
6  *(TAB)
7      START 130
8      TEXT: 'TAPEDED CHANNEL, MACRO ELEMENT MODEL
9      JLOC: 1 0. 9. 0. 0. 0. 0. 4 1 13
10         10 0. 4. 240. 0. 0. 240.
11         7 18. 0. 0. 18. 9. 0. 4 1 13
12         10 8. 0. 240. 8. 4. 240.
13         4 0. 0. 0. 18. 0. 0. 4 1 13
14         10 0. 0. 240. 8. 0. 240.
15      MATC: 1 30.+06 .3 .28 .1-4
16      SA: 1 .5
17      CON=1:FIXED PLANE=3
18  *(ELD)
19      E43
20      GROUP 1'TAPERED CHANNEL, TOP FLANGE
21          1 2 12 11 1 3 12
22      GROUP 2'TAPERED CHANNEL, BOTTOM FLANGE
23          7 8 18 17 1 3 12
24      GROUP 3'TAPERED CHANNEL, WEB
25          4 5 15 14 1 3 12
26  *(BN)
27      31:34: 61:64: 91:94: 121:124
28  *                                                END
29  $ DEFINE THE SYSTEM MODEL:
30  *(SYS DATA)                                END
31  $ SYSTEM PARAMETERS:
32      G=386.$ ACCELERATION OF GRAVITY
33  *(TAB)                                ENDTAB
34      START 45
35      JLOC: 1 0. 336. 0. 0. 48. 0. 4 2 5
36          9 240. 336. 0. 240. 48. 0.
37          2 0. 327. 0. 0. 39. 0. 4 2 5
38          9 240. 332. 0. 240. 44. 0.
39          9 0. 0. 0. 240. 0. 0. 5 9
40      MATC: 1 30.+6 .3 .2 1.-4
41      SA: 1 .5
42      ALTR: !IALT=2: !YLOC=48.: !NDO=4
43  *                                                LABEL 100
44          "IALT" 3 180. 2 -90. 1 0. 0. "YLOC" 0.
45          !IALT=IALT+1: !YLOC=YLOC+96.
46  *                                                JGZ,-1(NDO,100)
47      CON=1:FIXED PLANE=1: ZERO 2 3 4 5 6: 18,45,9
48  *                                ENDTAB
49  *(ELD)
50      E41: 9 18 17 8 1 4 8
51  *                                                END
52  $

```

```
53 $ DEFINE THE MACRO ELEMENT CONNECTIVITIES:
54 *(10 SJC CHNL 2)
55 17:16: 26:25: 35:34: 44:43
56 *(10 SJC CHNL 3)
57 15:14: 24:23: 33:32: 42:41
58 *(10 SJC CHNL 4)
59 13:12: 22:21: 31:30: 40:39
60 *(10 SJC CHNL 5)
61 11:10: 20:19: 29:28: 38:37
62 $
63 $ FORM THE SYSTEM MASS AND STIFFNESS MATRICES:
64 *CALL(ME SYS)
65 $
66 $ COMPUTE THE STATIC SOLUTION:
67 *XQT AUS
68 ALPHA: CASE TITLE: 1'DEAD WEIGHT + 20 LBS/SQ FT + MECHANICAL LOADS
69 TABLE: NODAL PRESSURE: J=1,45: .1389
70 R=RIGID(0. 0. 0.): DEFINE R3=R AUS 1 1 3,3
71 APPL FORC= PROD(386. MSYS, R3)
72 SYSVEC,U: APPL FORC: I=3: DDATA=50.: J=19,25,2: 50.
73 DDATA=50.: J=20,26,2: 50.
74 *XQT EQNF
75 *XQT DRSI
76 RESET K=KSYS
77 *XQT SSOL
78 RESET K=KSYS
79 *XQT VPRT
80 PRINT STAT DISP: PRINT STAT REAC
81 $
82 $ BACK TRANSFORM FOR MACRO ELEMENT DISPLACEMENT VECTORS:
83 *CALL(ME BACK)
84 $
85 $ PRINT THE MACRO ELEMENT MEMBRANE STRESS RESULTANTS:
86 *XQT U1
87 *(ES ALL)
88 NODES=0: DISPLAY=MSR
89 *CALL(ME ES)
90 $
91 $ PRINT THE MACRO ELEMENT DISPLACEMENT VECTORS:
92 *CALL(ME VPRT)
93 $
94 $ PRINT THE MACRO ELEMENT REACTION VECTORS:
95 *XQT U1
96 *(VPRT PARAMETERS)
97 N1=REAC
98 *CALL(ME VPRT)
```

STATIC DISPLACEMENTS.

| JOINT | 1 | | 2 | | 3 | | 4 | | 5 | | ID= | 1/ | 1/ | 1 |
|-------|---------|---|----------|---|---------|---|----------|---|----------|---|-----|----------|----|---|
| | | * | | * | | * | | * | | * | | 6 | | * |
| 1 | .000 | * | .000 | * | .000 | * | .000 | * | .000 | * | | .000 | | * |
| 2 | .000 | * | .000 | * | .000 | * | .000 | * | .000 | * | | .000 | | * |
| 3 | .000 | * | .000 | * | .000 | * | .000 | * | .000 | * | | .000 | | * |
| 4 | .000 | * | .000 | * | .000 | * | .000 | * | .000 | * | | .000 | | * |
| 5 | .000 | * | .000 | * | .000 | * | .000 | * | .000 | * | | .000 | | * |
| 6 | .000 | * | .000 | * | .000 | * | .000 | * | .000 | * | | .000 | | * |
| 7 | .000 | * | .000 | * | .000 | * | .000 | * | .000 | * | | .000 | | * |
| 8 | .000 | * | .000 | * | .000 | * | .000 | * | .000 | * | | .000 | | * |
| 9 | .000 | * | .000 | * | .000 | * | .000 | * | .000 | * | | .000 | | * |
| 10 | .215-02 | | -.100-02 | | .337-01 | | -.975-02 | | -.991-03 | | | -.703-04 | | |
| 11 | .178-02 | | -.931-03 | | .122+00 | | -.128-01 | | -.267-02 | | | -.957-04 | | |
| 12 | .169-02 | | -.404-03 | | .455-01 | | -.110-01 | | -.137-02 | | | -.845-04 | | |
| 13 | .158-02 | | -.374-03 | | .143+00 | | -.140-01 | | -.334-02 | | | -.118-03 | | |
| 14 | .166-02 | | -.187-03 | | .461-01 | | -.111-01 | | -.138-02 | | | -.848-04 | | |
| 15 | .154-02 | | -.162-03 | | .145+00 | | -.141-01 | | -.339-02 | | | -.118-03 | | |
| 16 | .147-02 | | -.196-04 | | .353-01 | | -.715-02 | | -.106-02 | | | -.546-04 | | |
| 17 | .142-02 | | .562-06 | | .976-01 | | -.869-02 | | -.245-02 | | | -.754-04 | | |
| 18 | .104-02 | | .000 | * | .000 | * | .000 | * | .000 | * | | .000 | * | |
| 19 | .279-02 | | -.104-02 | | .110+00 | | -.272-01 | | -.131-02 | | | -.127-03 | | |
| 20 | .281-02 | | -.102-02 | | .294+00 | | -.296-01 | | -.364-02 | | | -.126-03 | | |
| 21 | .268-02 | | -.666-03 | | .150+00 | | -.320-01 | | -.188-02 | | | -.157-03 | | |
| 22 | .263-02 | | -.643-03 | | .367+00 | | -.346-01 | | -.467-02 | | | -.157-03 | | |
| 23 | .254-02 | | -.335-03 | | .152+00 | | -.326-01 | | -.189-02 | | | -.158-03 | | |
| 24 | .249-02 | | -.323-03 | | .374+00 | | -.354-01 | | -.472-02 | | | -.157-03 | | |
| 25 | .224-02 | | -.122-03 | | .117+00 | | -.224-01 | | -.145-02 | | | -.101-03 | | |
| 26 | .221-02 | | -.115-03 | | .268+00 | | -.242-01 | | -.338-02 | | | -.986-04 | | |
| 27 | .186-02 | | .000 | * | .000 | * | .000 | * | .000 | * | | .000 | * | |
| 28 | .317-02 | | -.858-03 | | .198+00 | | -.504-01 | | -.135-02 | | | -.135-03 | | |
| 29 | .308-02 | | -.855-03 | | .467+00 | | -.520-01 | | -.356-02 | | | -.126-03 | | |
| 30 | .311-02 | | -.698-03 | | .277+00 | | -.598-01 | | -.199-02 | | | -.167-03 | | |
| 31 | .308-02 | | -.689-03 | | .595+00 | | -.614-01 | | -.463-02 | | | -.158-03 | | |
| 32 | .291-02 | | -.441-03 | | .279+00 | | -.606-01 | | -.199-02 | | | -.167-03 | | |
| 33 | .287-02 | | -.431-03 | | .602+00 | | -.622-01 | | -.465-02 | | | -.157-03 | | |
| 34 | .256-02 | | -.170-03 | | .214+00 | | -.408-01 | | -.154-02 | | | -.104-03 | | |
| 35 | .253-02 | | -.158-03 | | .431+00 | | -.416-01 | | -.330-02 | | | -.979-04 | | |
| 36 | .233-02 | | .000 | * | .000 | * | .000 | * | .000 | * | | .000 | * | |
| 37 | .307-02 | | -.678-03 | | .277+00 | | -.761-01 | | -.133-02 | | | -.124-03 | | |
| 38 | .314-02 | | -.683-03 | | .584+00 | | -.762-01 | | -.431-02 | | | -.125-03 | | |
| 39 | .319-02 | | -.669-03 | | .398+00 | | -.906-01 | | -.198-02 | | | -.156-03 | | |
| 40 | .319-02 | | -.672-03 | | .762+00 | | -.906-01 | | -.495-02 | | | -.156-03 | | |
| 41 | .300-02 | | -.549-03 | | .400+00 | | -.917-01 | | -.198-02 | | | -.156-03 | | |
| 42 | .298-02 | | -.547-03 | | .768+00 | | -.917-01 | | -.495-02 | | | -.156-03 | | |
| 43 | .266-02 | | -.251-03 | | .308+00 | | -.614-01 | | -.155-02 | | | -.971-04 | | |
| 44 | .265-02 | | -.239-03 | | .553+00 | | -.613-01 | | -.301-02 | | | -.969-04 | | |
| 45 | .253-02 | | .000 | * | .000 | * | .000 | * | .000 | * | | .000 | * | |

PAGE 1 STRESS DATA FOR MACRO ELEMENT CHNL, NREF= 2
S/C 1/ 1 DEAD WEIGHT + 20 LBS/SQ FT + MECHANICAL LOADS
E43 TAPERED CHANNEL, TOP FLANGE

GRP-IND*/

| JOINTS | NX | NY | NXY | ANG | MAX PN | MIN PN | MAX SHR |
|--------|----------|----------|----------|------|----------|----------|---------|
| 1- 1* | .114+03 | .803+03 | .137+03 | 79. | .829+03 | .878+02 | .371+03 |
| 1- 2* | .154+03 | .876+03 | .973+02 | 82. | .889+03 | .141+03 | .374+03 |
| 1- 3* | .131+03 | .907+03 | .490+02 | 86. | .910+03 | .128+03 | .391+03 |
| 1- 4* | -.289+01 | .466+03 | -.673+02 | 98. | .475+03 | -.124+02 | .244+03 |
| 1- 5* | -.299+02 | .382+03 | .952+02 | 78. | .403+03 | -.508+02 | .227+03 |
| 1- 6* | -.693+01 | .483+03 | .280+03 | 66. | .610+03 | -.134+03 | .372+03 |
| 1- 7* | -.655+02 | -.111+03 | .162+03 | 41. | .752+02 | -.251+03 | .163+03 |
| 1- 8* | -.555+02 | .110+02 | .119+03 | 53. | .102+03 | -.146+03 | .124+03 |
| 1- 9* | -.767+02 | -.194+03 | .646+02 | 24. | -.481+02 | -.223+03 | .873+02 |
| 1- 10* | .952+02 | .667+03 | .201+03 | 72. | .731+03 | .316+02 | .349+03 |
| 1- 11* | .935+02 | .572+03 | .818+02 | 81. | .586+03 | .799+02 | .253+03 |
| 1- 12* | .119+03 | .754+03 | -.446+02 | 94. | .757+03 | .116+03 | .321+03 |
| 1- 13* | .734+01 | .225+03 | -.123+03 | 114. | .281+03 | -.480+02 | .164+03 |
| 1- 14* | .139+02 | .236+03 | .842+02 | 71. | .265+03 | -.143+02 | .139+03 |
| 1- 15* | -.907+01 | .180+03 | .315+03 | 53. | .414+03 | -.243+03 | .328+03 |
| 1- 16* | -.933+02 | -.358+03 | .188+03 | 27. | .445+01 | -.455+03 | .230+03 |
| 1- 17* | -.102+03 | -.321+03 | .112+03 | 23. | -.552+02 | -.369+03 | .157+03 |
| 1- 18* | -.882+02 | -.396+03 | .109+02 | 2. | -.878+02 | -.396+03 | .154+03 |
| 1- 19* | .528+02 | .401+03 | .116+03 | 73. | .435+03 | .179+02 | .209+03 |
| 1- 20* | .632+02 | .358+03 | .398+02 | 82. | .364+03 | .580+02 | .153+03 |
| 1- 21* | .689+02 | .443+03 | -.191+02 | 93. | .444+03 | .679+02 | .188+03 |
| 1- 22* | .109+02 | .108+03 | -.730+02 | 118. | .147+03 | -.283+02 | .876+02 |
| 1- 23* | .927+01 | .106+03 | .550+02 | 66. | .131+03 | -.157+02 | .731+02 |
| 1- 24* | -.127+01 | .686+02 | .175+03 | 51. | .212+03 | -.144+03 | .178+03 |
| 1- 25* | -.755+02 | -.297+03 | .108+03 | 22. | -.318+02 | -.340+03 | .154+03 |
| 1- 26* | -.745+02 | -.276+03 | .535+02 | 14. | -.612+02 | -.289+03 | .114+03 |
| 1- 27* | -.656+02 | -.301+03 | .500+01 | 1. | -.655+02 | -.302+03 | .118+03 |
| 1- 28* | .104+02 | .157+03 | .398+02 | 76. | .167+03 | .271+00 | .833+02 |
| 1- 29* | .861+01 | .119+03 | .211+02 | 79. | .122+03 | .470+01 | .589+02 |
| 1- 30* | .904+01 | .140+03 | -.261+01 | 91. | .140+03 | .899+01 | .656+02 |
| 1- 31* | .484+01 | -.631+00 | -.221+02 | 139. | .244+02 | -.202+02 | .223+02 |
| 1- 32* | .115+02 | .351+02 | .143+02 | 65. | .419+02 | .480+01 | .185+02 |
| 1- 33* | .100+02 | .334+02 | .527+02 | 51. | .757+02 | -.322+02 | .540+02 |
| 1- 34* | -.359+02 | -.107+03 | .265+02 | 18. | -.270+02 | -.115+03 | .442+02 |
| 1- 35* | -.382+02 | -.121+03 | .107+02 | 7. | -.369+02 | -.122+03 | .425+02 |
| 1- 36* | -.362+02 | -.117+03 | -.505+01 | 176. | -.358+02 | -.117+03 | .406+02 |

PAGE 2 STRESS DATA FOR MACRO ELEMENT CHNL, NREF= 4
 S/C 1/ 1 DEAD WEIGHT + 20 LBS/SQ FT + MECHANICAL LOADS
 E43 TAPERED CHANNEL, BOTTOM FLANGE

GRP-IND*/

| JOINTS | NX | NY | NXY | ANG | MAX PN | MIN PN | MAX SHR |
|--------|----------|----------|----------|------|----------|----------|---------|
| 2- 1* | -.538+03 | -.442+04 | -.863+02 | 179. | -.536+03 | -.443+04 | .195+04 |
| 2- 2* | -.115+03 | -.108+04 | -.131+03 | 172. | -.974+02 | -.109+04 | .499+03 |
| 2- 3* | .301+03 | .224+04 | -.113+03 | 93. | .225+04 | .294+03 | .978+03 |
| 2- 4* | .157+03 | -.366+04 | -.602+02 | 179. | .158+03 | -.366+04 | .191+04 |
| 2- 5* | .385+02 | -.117+04 | -.147+03 | 173. | .562+02 | -.119+04 | .622+03 |
| 2- 6* | -.739+02 | .137+04 | -.110+03 | 94. | .138+04 | -.822+02 | .729+03 |
| 2- 7* | -.193+02 | -.304+04 | -.923+02 | 178. | -.165+02 | -.304+04 | .151+04 |
| 2- 8* | .738+01 | -.127+04 | -.110+03 | 175. | .169+02 | -.128+04 | .647+03 |
| 2- 9* | .220+02 | .480+03 | -.714+02 | 99. | .491+03 | .111+02 | .240+03 |
| 2- 10* | .182+02 | -.262+04 | -.437+02 | 179. | .189+02 | -.262+04 | .132+04 |
| 2- 11* | .307+01 | -.144+04 | -.755+02 | 177. | .701+01 | -.144+04 | .724+03 |
| 2- 12* | -.335+01 | -.238+03 | -.415+02 | 170. | .378+01 | -.245+03 | .124+03 |
| 2- 13* | -.110+02 | -.209+04 | -.192+02 | 179. | -.108+02 | -.209+04 | .104+04 |
| 2- 14* | .260+01 | -.149+04 | -.611+02 | 178. | .510+01 | -.149+04 | .747+03 |
| 2- 15* | .825+01 | -.909+03 | -.301+02 | 178. | .923+01 | -.910+03 | .459+03 |
| 2- 16* | .314+02 | -.136+04 | -.991+01 | 180. | .314+02 | -.136+04 | .697+03 |
| 2- 17* | .107+02 | -.149+04 | -.508+02 | 178. | .124+02 | -.149+04 | .752+03 |
| 2- 18* | -.602+01 | -.159+04 | -.971+01 | 180. | -.596+01 | -.159+04 | .793+03 |
| 2- 19* | .776+01 | -.105+04 | .161+02 | 1. | .801+01 | -.105+04 | .529+03 |
| 2- 20* | .279+01 | -.150+04 | .265+02 | 1. | .325+01 | -.150+04 | .753+03 |
| 2- 21* | -.647+01 | -.198+04 | .372+02 | 1. | -.577+01 | -.198+04 | .985+03 |
| 2- 22* | -.171+02 | -.730+03 | .605+02 | 5. | -.120+02 | -.735+03 | .362+03 |
| 2- 23* | -.613+01 | -.143+04 | .193+02 | 1. | -.587+01 | -.143+04 | .711+03 |
| 2- 24* | .774+01 | -.212+04 | .313+02 | 1. | .820+01 | -.212+04 | .106+04 |
| 2- 25* | .268+02 | -.165+03 | .473+02 | 13. | .378+02 | -.176+03 | .107+03 |
| 2- 26* | .766+01 | -.123+04 | .288+02 | 1. | .833+01 | -.123+04 | .620+03 |
| 2- 27* | -.140+02 | -.230+04 | .406+02 | 1. | -.133+02 | -.230+04 | .114+04 |
| 2- 28* | .496+01 | -.336+02 | .917+02 | 39. | .794+02 | -.108+03 | .937+02 |
| 2- 29* | -.359+01 | -.104+04 | .966+02 | 5. | .534+01 | -.105+04 | .527+03 |
| 2- 30* | -.113+02 | -.205+04 | .747+02 | 2. | -.858+01 | -.205+04 | .102+04 |
| 2- 31* | -.528+01 | -.567+02 | .110+03 | 38. | .818+02 | -.144+03 | .113+03 |
| 2- 32* | -.103+02 | -.715+03 | .916+02 | 7. | .146+01 | -.727+03 | .364+03 |
| 2- 33* | -.137+02 | -.138+04 | .570+02 | 2. | -.114+02 | -.138+04 | .684+03 |
| 2- 34* | -.152+02 | .197+02 | .113+03 | 49. | .117+03 | -.112+03 | .115+03 |
| 2- 35* | .400+01 | -.257+03 | .987+02 | 19. | .371+02 | -.290+03 | .164+03 |
| 2- 36* | .216+02 | -.534+03 | .496+02 | 5. | .260+02 | -.538+03 | .282+03 |

DISPLACEMENTS, MACRO ELEMENT CHNL, NREF= 3
 SET= 1, CON= 1, VECTOR= 1
 DEAD WEIGHT + 20 LBS/SQ FT + MECHANICAL LOADS

| JOINT | 1 | 2 | 3 | 4 | 5 | 6 |
|-------|----------|----------|----------|-----------|----------|-----------|
| 1 | .000 * | .000 * | .000 * | .000 * | .000 * | .000 * |
| 2 | .000 * | .000 * | .000 * | .000 * | .000 * | .000 * |
| 3 | .000 * | .000 * | .000 * | .000 * | .000 * | .000 * |
| 4 | .000 * | .000 * | .000 * | .000 * | .000 * | .000 * |
| 5 | .000 * | .000 * | .000 * | .000 * | .000 * | .000 * |
| 6 | .000 * | .000 * | .000 * | .000 * | .000 * | .000 * |
| 7 | .000 * | .000 * | .000 * | .000 * | .000 * | .000 * |
| 8 | .000 * | .000 * | .000 * | .000 * | .000 * | .000 * |
| 9 | .000 * | .000 * | .000 * | .000 * | .000 * | .000 * |
| 10 | .000 * | .000 * | .000 * | .000 * | .000 * | .000 * |
| 11 | .154-01 | -.206-03 | .116-02 | -.559-04 | .144-02 | -.817-03 |
| 12 | .123-01 | -.148-03 | .129-02 | -.398-04 | .118-02 | -.863-03 |
| 13 | .916-02 | -.985-04 | .138-02 | -.306-04 | .916-03 | -.884-03 |
| 14 | .599-02 | -.330-04 | .142-02 | -.157-04 | .667-03 | -.883-03 |
| 15 | .600-02 | -.605-02 | -.151-02 | .496-03 | .488-03 | -.821-03 |
| 16 | .635-02 | -.113-01 | -.451-02 | .803-03 | .407-03 | -.771-03 |
| 17 | .701-02 | -.152-01 | -.770-02 | .642-03 | .339-03 | -.668-03 |
| 18 | .928-02 | -.149-01 | -.328-02 | .439-03 | .551-03 | -.654-03 |
| 19 | .115-01 | -.149-01 | .104-02 | .330-03 | .751-03 | -.625-03 |
| 20 | .135-01 | -.150-01 | .539-02 | .218-03 | .940-03 | -.574-03 |
| 21 | .590-01 | .116-03 | .200-02 | -.916-04 | .318-02 | -.411-02 |
| 22 | .467-01 | .117-03 | .187-02 | -.773-04 | .246-02 | -.423-02 |
| 23 | .343-01 | .129-03 | .197-02 | -.652-04 | .176-02 | -.422-02 |
| 24 | .222-01 | .129-03 | .233-02 | -.546-04 | .113-02 | -.412-02 |
| 25 | .223-01 | -.220-01 | -.325-02 | .989-03 | .933-03 | -.365-02 |
| 26 | .225-01 | -.409-01 | -.848-02 | .152-02 | .809-03 | -.319-02 |
| 27 | .229-01 | -.575-01 | -.138-01 | .115-02 | .712-03 | -.304-02 |
| 28 | .314-01 | -.573-01 | -.599-02 | .934-03 | .116-02 | -.307-02 |
| 29 | .398-01 | -.572-01 | .181-02 | .771-03 | .161-02 | -.307-02 |
| 30 | .483-01 | -.573-01 | .962-02 | .623-03 | .203-02 | -.306-02 |
| 31 | .145+00B | .162-03B | .154-02B | -.118-03B | .339-02B | -.141-01B |
| 32 | .110+00 | .171-03 | .187-02 | -.107-03 | .271-02 | -.137-01 |
| 33 | .765-01 | .182-03 | .193-02 | -.961-04 | .204-02 | -.127-01 |
| 34 | .461-01B | .187-03B | .166-02B | -.848-04B | .138-02B | -.111-01B |
| 35 | .461-01 | -.483-01 | -.452-02 | .104-02 | .127-02 | -.810-02 |
| 36 | .462-01 | -.868-01 | -.112-01 | .180-02 | .116-02 | -.675-02 |
| 37 | .465-01 | -.121+00 | -.181-01 | .157-02 | .107-02 | -.659-02 |
| 38 | .640-01 | -.121+00 | -.796-02 | .140-02 | .176-02 | -.677-02 |
| 39 | .818-01 | -.121+00 | .215-02 | .124-02 | .243-02 | -.683-02 |
| 40 | .996-01 | -.121+00 | .123-01 | .109-02 | .307-02 | -.680-02 |
| 41 | .184+00 | .314-03 | .282-02 | -.137-03 | .348-02 | -.143-01 |
| 42 | .148+00 | .349-03 | .274-02 | -.130-03 | .288-02 | -.144-01 |
| 43 | .112+00 | .369-03 | .282-02 | -.123-03 | .226-02 | -.144-01 |
| 44 | .762-01 | .407-03 | .309-02 | -.112-03 | .158-02 | -.143-01 |
| 45 | .762-01 | -.691-01 | -.515-02 | .109-02 | .151-02 | -.138-01 |
| 46 | .763-01 | -.136+00 | -.131-01 | .206-02 | .143-02 | -.134-01 |
| 47 | .765-01 | -.200+00 | -.212-01 | .204-02 | .137-02 | -.132-01 |
| 48 | .109+00 | -.200+00 | -.941-02 | .189-02 | .223-02 | -.132-01 |
| 49 | .141+00 | -.200+00 | .240-02 | .176-02 | .306-02 | -.132-01 |
| 50 | .173+00 | -.200+00 | .142-01 | .163-02 | .388-02 | -.131-01 |

REACTIONS, MACRO ELEMENT CHNL, NREF= 5
 SET= 1, CON= 1, VECTOR= 1
 DEAD WEIGHT + 20 LBS/SQ FT + MECHANICAL LOADS

| JOINT | 1 | 2 | 3 | 4 | 5 | 6 |
|-------|-----------|-----------|-----------|-----------|-----------|-----------|
| 1 | -.372+03* | .168+04* | -.213+04* | .620+03* | -.904+03* | -.531+03* |
| 2 | -.110+02* | .565+03* | -.223+04* | .648+03* | -.776+02* | -.938+03* |
| 3 | .760+01* | .172+03* | -.252+04* | .433+03* | -.131+02* | -.942+03* |
| 4 | -.343+03* | -.185+04* | -.380+04* | .385+03* | -.142+03* | -.701+03* |
| 5 | .209+04* | .347+02* | .460+04* | -.182+03* | -.112+04* | -.428+03* |
| 6 | .215+04* | .891+02* | .154+05* | -.469+03* | -.954+03* | -.151+03* |
| 7 | -.699+04* | .559+04* | .181+05* | -.659+04* | .537+03* | -.665+03* |
| 8 | -.234+03* | -.485+04* | .497+04* | -.654+04* | -.134+03* | -.103+04* |
| 9 | .134+03* | -.479+04* | -.403+04* | -.457+04* | -.162+03* | -.873+03* |
| 10 | -.455+02* | .508+04* | -.509+04* | -.882+03* | -.653+03* | -.407+03* |
| 11 | -.164-02 | .198-02 | .946-03 | .212-04 | -.318-02 | -.244-02 |
| 12 | .206-02 | -.475-02 | -.897-03 | .573-04 | .122-03 | -.229-02 |
| 13 | .636-03 | .788-03 | -.672-03 | -.246-04 | .642-02 | .208-02 |
| 14 | -.103-02 | .130-02 | -.244-02 | -.180-03 | -.341-02 | .179-02 |
| 15 | .311-01 | .320-03 | .589-02 | -.460-03 | .230-04 | .878-03 |
| 16 | -.202-01 | -.181-03 | .140-02 | .951-03 | .198-04 | .100-02 |
| 17 | -.849-02 | .108-01 | .624-02 | -.980-03 | -.288-02 | .289-02 |
| 18 | .293-02 | .133-01 | .419-02 | -.398-03 | .319-02 | -.561-03 |
| 19 | -.443-02 | -.114+00 | -.504-03 | -.417-03 | -.606-02 | .186-02 |
| 20 | .273-02 | .890-01 | -.204-02 | -.354-03 | .535-02 | .352-02 |
| 21 | -.177-01 | -.134-01 | .472-03 | -.554-04 | -.184-01 | -.221-01 |
| 22 | .779-02 | .106-01 | .559-02 | .278-03 | .133-01 | -.353-01 |
| 23 | .152-01 | -.674-02 | .299-03 | .157-03 | .960-02 | -.480-02 |
| 24 | -.464-01 | .889-02 | -.231-02 | -.295-03 | -.457-02 | .580-02 |
| 25 | -.360-02 | .820-03 | .646-02 | -.290-03 | -.650-04 | .298-02 |
| 26 | -.288-01 | -.157-02 | -.244-01 | -.235-03 | -.808-04 | -.272-03 |
| 27 | .494-01 | .202+00 | .231-01 | -.208-02 | -.349-02 | .584-02 |
| 28 | .844-02 | -.118+00 | .800-02 | -.565-04 | .957-05 | .348-02 |
| 29 | -.655-02 | -.217+00 | .217-01 | -.109-02 | .155-01 | .556-03 |
| 30 | .373-02 | .133+00 | -.140-01 | .328-03 | -.137-01 | .372-02 |
| 31 | .736+03B | -.497+03B | -.344+04B | .403+00B | .163+03B | .108+03B |
| 32 | -.130-01 | .771-03 | -.133-01 | .987-04 | -.259-01 | -.197-01 |
| 33 | .121-01 | -.125-01 | -.331-03 | .228-03 | -.218-02 | -.117-01 |
| 34 | .414+03B | -.184+03B | -.657+04B | -.518+01B | -.130+03B | -.115+03B |
| 35 | -.428+00 | .300-02 | .147-01 | -.226-02 | .698-03 | .926-03 |
| 36 | -.131-01 | -.175-02 | -.345-03 | -.242-02 | .328-03 | .269-02 |
| 37 | .109+00 | -.256+00 | .251-01 | .331-03 | -.481-02 | .890-02 |
| 38 | .420-02 | .322+00 | -.498-01 | .363-02 | .403-02 | .595-02 |
| 39 | .273-01 | -.921-01 | .663-01 | -.140-02 | .282-01 | -.252-01 |
| 40 | -.242-01 | .394-01 | -.535-01 | .104-02 | -.278-01 | -.321-01 |
| 41 | .565-02 | -.453-01 | .139-01 | .140-03 | .174-01 | .817-02 |
| 42 | -.351-01 | .359-01 | -.237-01 | .735-03 | -.525-01 | -.321-01 |
| 43 | .379-01 | -.279-01 | .101-01 | .260-03 | .751-01 | -.188-01 |
| 44 | .324-01 | .327-01 | -.158-02 | -.754-03 | -.294-01 | .132-01 |
| 45 | -.154+00 | .747-03 | -.331-02 | .717-02 | -.584-03 | .427-02 |
| 46 | -.111+00 | .450-02 | -.125-01 | -.846-02 | .725-03 | .129-01 |
| 47 | .198+00 | -.951+00 | .311-01 | .288-02 | -.191-02 | .258-01 |
| 48 | .205-01 | .623+00 | -.225-01 | -.273-02 | .445-02 | .134-01 |
| 49 | .189-02 | .397-01 | .754-01 | -.528-02 | -.441-01 | -.141-01 |
| 50 | -.640-02 | .268+00 | -.657-01 | .469-02 | .403-01 | -.134-01 |

TABLE OF CONTENTS, LIBRARY 1

| SEQ | RR | DATE | TIME | E | WORDS | NJ | NI*NJ | T | DATA | SET | NAME | N4 |
|-----|------|--------|--------|---|-------|----|-------|----|------|------|------|-----|
| 1 | 17 | 811201 | 165240 | 0 | 18 | 1 | 18 | 0 | JDF1 | BTAB | 1 | 8 |
| 2 | 18 | 811201 | 165240 | 0 | 45 | 45 | 45 | 0 | JREF | BTAB | 2 | 6 |
| 3 | -20 | 811201 | 165240 | 0 | 12 | 1 | 12 | -1 | ALTR | BTAB | 2 | 4 |
| 4 | -21 | 811201 | 165240 | 0 | 45 | 1 | 45 | 0 | JSEQ | BTAB | 2 | 17 |
| 5 | -23 | 811201 | 165240 | 0 | 45 | 1 | 45 | 0 | SEQ | BTAB | 2 | 170 |
| 6 | 25 | 811201 | 165240 | 0 | 135 | 45 | 135 | -1 | JLOC | BTAB | 2 | 5 |
| 7 | 30 | 811201 | 165240 | 0 | 10 | 1 | 10 | -1 | MATC | BTAB | 2 | 2 |
| 8 | 31 | 811201 | 165240 | 0 | 43 | 1 | 43 | -1 | SA | BTAB | 2 | 13 |
| 9 | 33 | 811201 | 165240 | 0 | 60 | 5 | 60 | -1 | ALTR | BTAB | 2 | 4 |
| 10 | 36 | 811201 | 165240 | 0 | 45 | 45 | 45 | 0 | CON | | 1 | 0 |
| 11 | 38 | 811201 | 165240 | 0 | 405 | 45 | 405 | -1 | QJJT | BTAB | 2 | 19 |
| 12 | 53 | 811201 | 165244 | 0 | 512 | 56 | 896 | 0 | DEF | E41 | 9 | 4 |
| 13 | 85 | 811201 | 165244 | 0 | 2 | 1 | 2 | 0 | GD | E41 | 9 | 4 |
| 14 | 86 | 811201 | 165244 | 0 | 15 | 1 | 15 | 4 | GTIT | E41 | 9 | 4 |
| 15 | 87 | 811201 | 165244 | 0 | 20 | 1 | 20 | 0 | DIR | E41 | 9 | 4 |
| 16 | 88 | 811201 | 165244 | 0 | 1 | 1 | 1 | 4 | ELTS | NAME | 0 | 0 |
| 17 | 89 | 811201 | 165244 | 0 | 1 | 1 | 1 | 0 | ELTS | NNOD | 0 | 0 |
| 18 | 90 | 811201 | 165244 | 0 | 1 | 1 | 1 | 0 | ELTS | ISCT | 0 | 0 |
| 19 | 91 | 811201 | 165244 | 0 | 15 | 1 | 15 | 0 | NS | | 0 | 0 |
| 20 | 92 | 811201 | 165250 | 0 | 45 | 45 | 45 | 0 | CON | | 9999 | 0 |
| 21 | 94 | 811201 | 165416 | 0 | 7144 | 47 | 1786 | -1 | RK | BTAB | 6 | 0 |
| 22 | 350 | 811201 | 165416 | 0 | 7144 | 47 | 1786 | -1 | RM | BTAB | 6 | 0 |
| 23 | 606 | 811201 | 165431 | 0 | 5376 | 32 | 168 | 4 | E41 | EFIL | 9 | 4 |
| 24 | 798 | 811201 | 165427 | 0 | 270 | 45 | 270 | -1 | DEM | DIAG | 0 | 0 |
| 25 | 808 | 811201 | 165434 | 0 | 45 | 45 | 45 | 0 | SEQ | BTAB | 2 | 170 |
| 26 | 810 | 811201 | 165434 | 0 | 45 | 45 | 45 | 0 | JSEQ | BTAB | 2 | 17 |
| 27 | 812 | 811201 | 165441 | 0 | 1792 | 45 | 1792 | 0 | KMAP | TOPO | 233 | 23 |
| 28 | 876 | 811201 | 165441 | 0 | 896 | 1 | 896 | 0 | TAN | IMAP | 0 | 0 |
| 29 | 908 | 811201 | 165441 | 0 | 9 | 9 | 9 | 0 | TAN | STAT | 0 | 0 |
| 30 | 909 | 811201 | 165441 | 0 | 21 | 7 | 21 | 0 | TAN | TBCT | 0 | 0 |
| 31 | 910 | 811201 | 165441 | 0 | 8 | 8 | 8 | 0 | TAN | PBCT | 0 | 0 |
| 32 | 911 | 811201 | 165447 | 0 | 11200 | 45 | 2240 | 2 | K | SPAR | 36 | 0 |
| 33 | 1725 | 811201 | 165452 | 0 | 11200 | 45 | 2240 | 2 | KME | SPAR | 36 | 0 |
| 34 | 2525 | 811201 | 165452 | 0 | 11200 | 45 | 2240 | 1 | MME | SPAR | 36 | 0 |
| 35 | 2925 | 811201 | 165500 | 0 | 11200 | 45 | 2240 | 2 | KSYS | SPAR | 36 | 0 |
| 36 | 3725 | 811201 | 165500 | 0 | 11200 | 45 | 2240 | 1 | MSYS | SPAR | 36 | 0 |
| 37 | 4125 | 811201 | 165508 | 0 | 15 | 1 | 15 | 4 | CASE | TITL | 1 | 1 |
| 38 | 4126 | 811201 | 165508 | 0 | 45 | 45 | 45 | -1 | NODA | PRES | 1 | 1 |
| 39 | 4128 | 811201 | 165508 | 0 | 1620 | 45 | 270 | -1 | R | AUS | 1 | 1 |
| 40 | 4188 | 811201 | 165508 | 0 | 270 | 45 | 270 | -1 | APPL | FORC | 1 | 1 |
| 41 | 4198 | 811201 | 165514 | 0 | 270 | 45 | 270 | -1 | EQNF | FORC | 1 | 1 |
| 42 | 4208 | 811201 | 165517 | 0 | 12740 | 45 | 1820 | 1 | INV | KSYS | 1 | 0 |
| 43 | 4663 | 811201 | 165517 | 0 | 2 | 1 | 2 | 0 | XINV | KSYS | 1 | 0 |
| 44 | 4664 | 811201 | 165531 | 0 | 270 | 45 | 270 | -1 | STAT | DISP | 1 | 1 |
| 45 | 4674 | 811201 | 165531 | 0 | 270 | 45 | 270 | -1 | STAT | REAC | 1 | 1 |
| 46 | 4684 | 811201 | 165545 | 0 | 270 | 45 | 270 | -1 | SYS | JMG | 1 | 1 |

TABLE OF CONTENTS, LIBRARY 3

| SEQ | RR | DATE | TIME | R | WORDS | NJ | NI*NJ | T | DATA SET NAME | N3 | N4 |
|-----|----|--------|--------|---|--------|----|-------|---|---------------|----|----|
| 1 | 17 | 811201 | 165224 | 0 | 214536 | 1 | 19992 | 8 | LIB CHNL | 1 | 1 |

TABLE OF CONTENTS, LIBRARY 4

| SEQ | RR | DATE | TIME | R | WORDS | NJ | NI*NJ | T | DATA SET NAME | N3 | N4 |
|-----|-----|--------|--------|---|-------|----|-------|----|---------------|-----|-----|
| 1 | 17 | 811201 | 165307 | 0 | 1786 | 47 | 1786 | -1 | RK CHNL | 6 | 2 |
| 2 | 81 | 811201 | 165324 | 0 | 1786 | 47 | 1786 | -1 | RK CHNL | 6 | 3 |
| 3 | 145 | 811201 | 165342 | 0 | 1786 | 47 | 1786 | -1 | RK CHNL | 6 | 4 |
| 4 | 209 | 811201 | 165402 | 0 | 1786 | 47 | 1786 | -1 | RK CHNL | 6 | 5 |
| 5 | 273 | 811201 | 165414 | 0 | 1 | 1 | 1 | -1 | END END | 999 | 999 |

TABLE OF CONTENTS, LIBRARY 5

| SEQ | RR | DATE | TIME | R | WORDS | NJ | NI*NJ | T | DATA SET NAME | N3 | N4 |
|-----|-----|--------|--------|---|-------|----|-------|----|---------------|-----|-----|
| 1 | 17 | 811201 | 165307 | 0 | 1786 | 47 | 1786 | -1 | RM CHNL | 6 | 2 |
| 2 | 81 | 811201 | 165324 | 0 | 1786 | 47 | 1786 | -1 | RM CHNL | 6 | 3 |
| 3 | 145 | 811201 | 165342 | 0 | 1786 | 47 | 1786 | -1 | RM CHNL | 6 | 4 |
| 4 | 209 | 811201 | 165402 | 0 | 1786 | 47 | 1786 | -1 | RM CHNL | 6 | 5 |
| 5 | 273 | 811201 | 165414 | 0 | 1 | 1 | 1 | -1 | END END | 999 | 999 |

TABLE OF CONTENTS, LIBRARY 6

| SEQ | RR | DATE | TIME | R | WORDS | NJ | NI*NJ | T | DATA SET NAME | N3 | N4 |
|-----|----|--------|--------|---|-------|----|-------|---|---------------|----|----|
| 1 | 17 | 811201 | 165259 | 0 | 12 | 1 | 12 | 0 | SSBT CHNL | 2 | 0 |
| 2 | 18 | 811201 | 165316 | 0 | 12 | 1 | 12 | 0 | SSBT CHNL | 3 | 0 |
| 3 | 19 | 811201 | 165333 | 0 | 12 | 1 | 12 | 0 | SSBT CHNL | 4 | 0 |
| 4 | 20 | 811201 | 165352 | 0 | 12 | 1 | 12 | 0 | SSBT CHNL | 5 | 0 |

TABLE OF CONTENTS, LIBRARY 7

| SEQ | RR | DATE | TIME | E | WORDS | NJ | NI*NJ | T | DATA SET NAME | N3 | N4 |
|-----|-----|--------|--------|---|-------|-----|-------|----|---------------|----|----|
| | | | | R | | | | Y | N1 N2 | | |
| 1 | 17 | 811201 | 165508 | 0 | 15 | 1 | 15 | 4 | CASE TITL | 1 | 1 |
| 2 | 18 | 811201 | 165553 | 0 | 780 | 130 | 780 | -1 | USB CHNL | 1 | 2 |
| 3 | 46 | 811201 | 165553 | 0 | 780 | 130 | 780 | -1 | USB CHNL | 1 | 3 |
| 4 | 74 | 811201 | 165553 | 0 | 780 | 130 | 780 | -1 | USB CHNL | 1 | 4 |
| 5 | 102 | 811201 | 165553 | 0 | 780 | 130 | 780 | -1 | USB CHNL | 1 | 5 |
| 6 | 130 | 811201 | 165634 | 0 | 14 | 32 | 448 | 6 | HEAD CHNL | 2 | 0 |
| 7 | 146 | 811201 | 165642 | 0 | 14 | 32 | 448 | 6 | HEAD CHNL | 3 | 0 |
| 8 | 162 | 811201 | 165651 | 0 | 14 | 32 | 448 | 6 | HEAD CHNL | 4 | 0 |
| 9 | 178 | 811201 | 165659 | 0 | 14 | 32 | 448 | 6 | HEAD CHNL | 5 | 0 |
| 10 | 194 | 811201 | 165742 | 0 | 780 | 130 | 780 | -1 | REAC CHNL | 1 | 2 |
| 11 | 222 | 811201 | 165750 | 0 | 780 | 130 | 780 | -1 | REAC CHNL | 1 | 3 |
| 12 | 250 | 811201 | 165757 | 0 | 780 | 130 | 780 | -1 | REAC CHNL | 1 | 4 |
| 13 | 278 | 811201 | 165804 | 0 | 780 | 130 | 780 | -1 | REAC CHNL | 1 | 5 |

TABLE OF CONTENTS, LIBRARY 10

| SEQ | RR | DATE | TIME | E | WORDS | NJ | NI*NJ | T | DATA SET NAME | N3 | N4 |
|-----|----|--------|--------|---|-------|----|-------|---|---------------|----|----|
| | | | | R | | | | Y | N1 N2 | | |
| 1 | 17 | 811201 | 164925 | 0 | 14 | 32 | 448 | 6 | SJC CHNL | 2 | 0 |
| 2 | 33 | 811201 | 164925 | 0 | 14 | 32 | 448 | 6 | SJC CHNL | 3 | 0 |
| 3 | 49 | 811201 | 164925 | 0 | 14 | 32 | 448 | 6 | SJC CHNL | 4 | 0 |
| 4 | 65 | 811201 | 164925 | 0 | 42 | 32 | 448 | 6 | SJC CHNL | 5 | 0 |

TABLE OF CONTENTS, LIBRARY 29

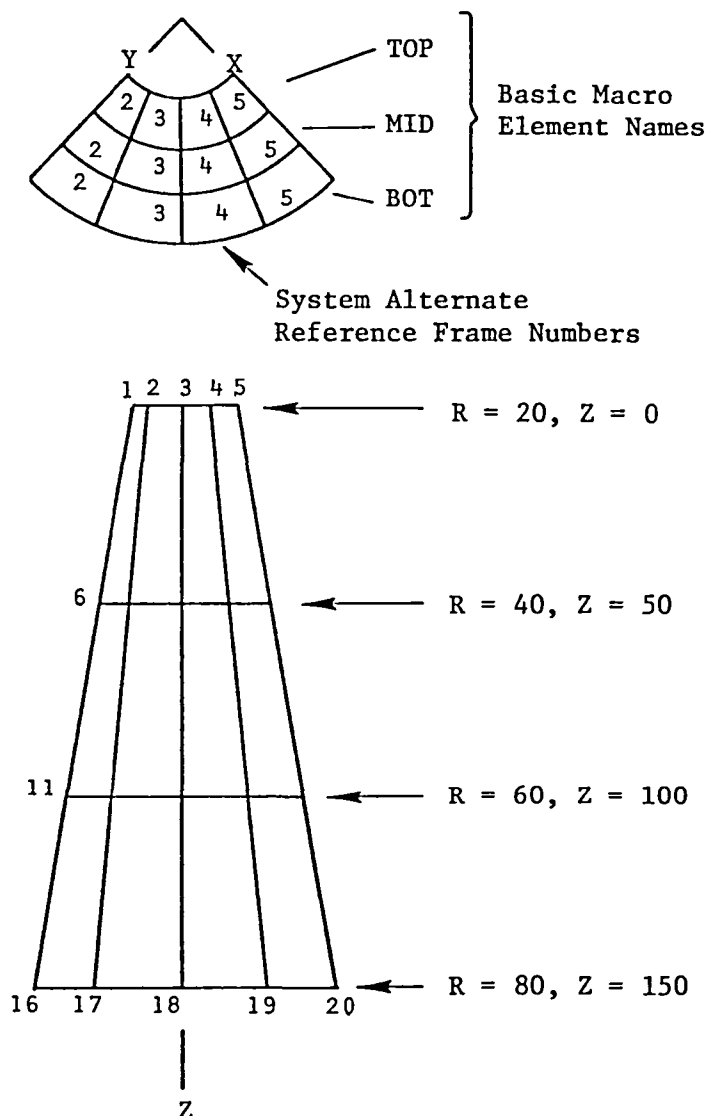
| SEQ | RR | DATE | TIME | E | WORDS | NJ | NI*NJ | T | DATA SET NAME | N3 | N4 |
|-----|-----|--------|--------|---|-------|----|-------|---|---------------|----|----|
| | | | | R | | | | Y | N1 N2 | | |
| 1 | 17 | 811201 | 164922 | 0 | 1372 | 32 | 448 | 6 | ME DOC | 1 | 0 |
| 2 | 81 | 811201 | 164925 | 0 | 336 | 32 | 448 | 6 | CHNL DATA | 1 | 0 |
| 3 | 97 | 811201 | 164925 | 0 | 280 | 32 | 448 | 6 | SYS DATA | 0 | 0 |
| 4 | 113 | 811201 | 165734 | 0 | 336 | 3 | 336 | 0 | REGI HOUS | 1 | 1 |

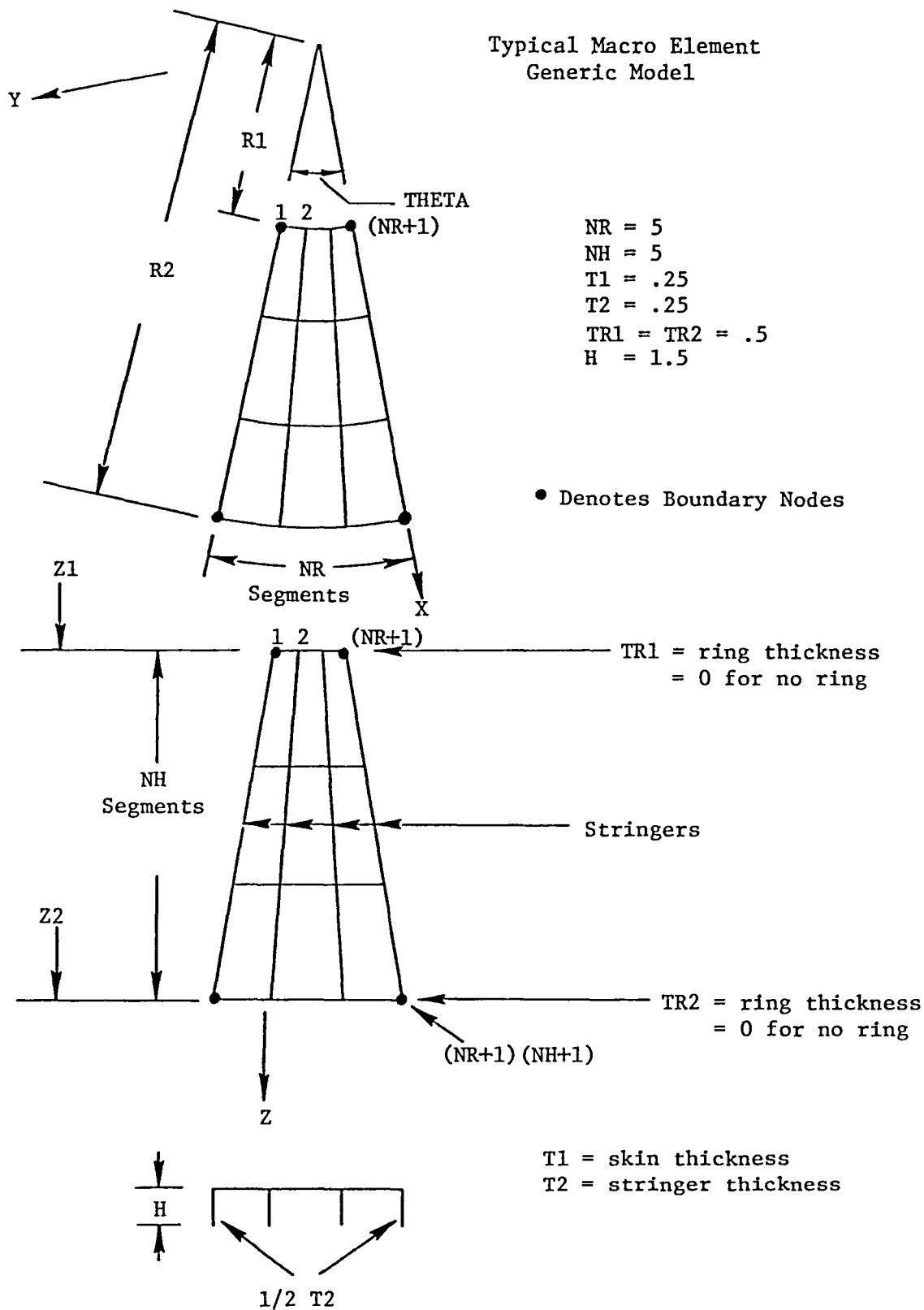
6.2 VIBRATIONAL MODES OF A STRINGER STIFFENED CONICAL SHELL

The EAL macro element procedures were used to compute the vibrational modes and frequencies of the stiffened conical shell shown below. As illustrated, the system model consists of 12 macro elements. Each of three unique macro elements is repeated four times. A generic model runstream element named GENERIC CONE was used to generate the finite element model for each of the three basic macro elements. The macro element generic model is illustrated on page 6.2-2. The input runstream for the problem and a listing of GENERIC CONE are shown on pages 6.2-3 through 6.2-6. Sample printout of the computed modes are shown on pages 6.2-7 through 6.2-11. Tables of contents for all pertinent EAL libraries are shown on pages 6.2-12 through 6.2-14.

$E = 30 \times 10^6$
 $\nu = .3$
 $\rho = .28$
 skin $t = .25$
 stringer $t = .25$
 @4.5° increments
 ring $t = .5$ @ large and
 small circles
 ring and stringer depth = 4

XZ = YZ = symmetry plane
 Z-direction displacement
 constrained at joints 16-20





typical cross section,
 stringers at each
 finite element boundary

```

1  *XQT U1
2  $
3  $ MACRO ELEMENT, TOP CONICAL SEGMENT:
4  *(TOP DATA 1)                                END
5  $ GRAVITY                                GENERIC CONE PARAMETERS
6    G=386.          R1=20., Z1=0., R2=40., Z2=50., TR1=.5
7  *DCALL(29 GENERIC CONE)
8  *                                END
9  $
10 $ MACRO ELEMENT, MIDDLE CONICAL SEGMENT:
11 *(MID DATA 1)                                END
12 $ GRAVITY                                GENERIC CONE PARAMETERS
13   G=386.          R1=40., Z1=50., R2=60., Z2=100.
14 *DCALL(29 GENERIC CONE)
15 *                                END
16 $
17 $ MACRO ELEMENT, BOTTOM CONICAL SEGMENT:
18 *(BOT DATA 1)                                END
19 $ GRAVITY                                GENERIC CONE PARAMETERS
20   G=386.          R1=60., Z1=100., R2=80., Z2=150., TR2=.5
21 *DCALL(29 GENERIC CONE)
22 *                                END
23 $
24 $ SYSTEM DATA:
25 *(SYS DATA)                                ENDSYS
26 *(TAB)                                END
27   START    20
28   JLOC:    FORMAT=2: 1  20.  90.   0.  20.   0.   0.   5 1 4
29                5  80.  90. 150.  80.   0. 150.
30   JREF:    NREF=-1: 1,20
31   CON=1:   ZERO 3: 16, 20: SYMM PLANE=1: SYMM PLANE=2
32   ALTR:    !NR=4: !T=67.5: !IAL=2
33 *                                LABEL 100
34   "IAL" 3 "T": !IAL=IAL+1: !T=T-22.5
35 *                                JGZ,-1(NR,100)
36 *                                END
37 *                                ENDSYS
38 $ SET UP THE SJC DATA SETS IN LIB 10:
39 $
40 *XQT U3
41   !NDO=3: !N=-1: !N2='TOP
42 *                                LABEL 1000
43   !MDO=4: !NREF=1: !N=N+1
44 *                                LABEL 2000
45   !NREF=NREF+1: !N=N+1: !N1=N+1: !N6=N+6: !N5=N+5
46   RP2
47   OUTP=10 SJC "N2" "NREF" 0: FORMAT 1'(3(I4,1H:),I4)
48   PRINT(1) "N" "N1" "N5" "N6"
49 *                                JGZ,-1(MDO,2000)
50   !TST=NDO-3: !N2='MID
51 *                                JZ(TST,200)
52   !N2='BOT

```

ME DOC 2 0

CREATED: 811201 180633

PRINTED: 811201 180633

```
53      *                                LABEL 200
54      *                                JGZ,-1(NDO,1000)
55      $ FORM THE SYSTEM MASS AND STIFFNESS MATRICES:
56      $
57      *CALL(ME SYS)
58      $ COMPUTE THE SYSTEM MODES AND FREQUENCIES:
59      $
60      *XQT E4
61      RESET M=MSYS, K=KSYS, NMODES=3, ICA=1
62      *XQT VPRT
63      PRINT VIBR MODE
64      $ BACK TRANSFORM FOR AND PRINT MACRO ELEMENT EIGENVECTORS:
65      $
66      *XQT U1
67      *(BACK PARAMETERS)
68      VECT=VIBR
69      *(VPRT PARAMETERS)
70      EVAL=VIBR
71      *CALL(ME BACK)
72      *CALL(ME VPRT)
```

```

1  *XQT U1
2  *(TAB)                                ENDTAB
3  $
4  $ REGISTERS THAT ARE COMMON TO ALL MACRO ELEMENTS:
5      !THET=22.5: !NR=5: !NH=5: !T1=.25: !T2=.25: !H=1.5
6  $
7  $ CONICAL SEGMENT REGISTERS:
8  $   NR=   NUMBER OF RADIAL SUBDIVISIONS
9  $   NH=   NUMBER OF LONGITUDINAL SUBDIVISIONS
10 $   R1,Z1=RADIUS AND Z LOCATION OF END 1
11 $   R2,Z2=RADIUS AND Z LOCATION OF END 2
12 $   THET= ANGULAR DIMENSION IN DEGREES
13 $   H=    RING AND STRINGER DEPTH
14 $   T1=   SKIN THICKNESS
15 $   T2=   STRINGER THICKNESS
16 $   TR1=  RING 1 THICKNESS, OMIT THIS REGISTER FOR FOR NO RING 1
17 $   TR2=  RING 2 THICKNESS, OMIT THIS REGISTER FOR FOR NO RING 2
18 $
19     !NR1=NR+1: !NH1=NH+1: !NR2=NR+2: !NR3=NR+3: !JT1=NR1*NH1
20     !K1=JT1+1: !K2=JT1+2: !KNR1=JT1+NR1: !KNR2=JT1+NR2
21     !KNR3=JT1+NR3: !NRM1=NR-1: !NRH1=NR+1*NH: !BN3=NRH1+1
22     !JT=2*JT1: !R1S=R1-H: !R2S=R2-H: !T2H=.5*T2
23     !LTR1=LOCA(TR1): !LTR2=LOCA(TR2)
24 START "JT"
25 JLOC: FORMAT=2
26     1   "R1"  "THET"  "Z1"  "R1"  0.  "Z1"  "NR1"  1  "NR1"
27     "NH1" "R2"  "THET"  "Z2"  "R2"  0.  "Z2"
28     "K1"  "R1S" "THET"  "Z1"  "R1S" 0.  "Z1"  "NR1"  1  "NR1"
29     "NH1" "R2S" "THET"  "Z2"  "R2S" A\ "Z2"
30 JREF: NREF=-1: 1,"JT"
31 CON=1
32 MATC: 1 30.+6 .3 .28 .1-4
33 SA:   1 "T1"  $ SKIN
34       2 "T2"  $ INTERIOR STRINGERS
35       3 "T2H" $ EXTERIOR STRINGERS
36 *                                           JZ(LTR1,100)
37     4 "TR1" $ END RING 1
38 *                                           LABEL 100
39 *                                           JZ(LTR2,200)
40     5 "TR2" $ END RING 2
41 *                                           LABEL 200
42 *                                           RETURN
43 *                                           ENDTAB
44 *(ELD)                                       ENDELD
45 E43: GROUP 1'CONICAL SEGMENT SKIN
46     1 2 "NR3" "NR2" 1 "NR" "NH"
47 GROUP 2'CONICAL SEGMENT STRINGERS
48     NSECT=3: 1 "NR2" "KNR2" "K1" 1 "NH" 1 2 "NR"
49     NSECT=2: 2 "NR3" "KNR3" "K2" 1 "NH" 1 "NRM1" 1
50     !TEST=LTR1+LTR2
51 *                                           JZ(TEST,200)
52 GROUP 3'CONICAL SEGMENT RINGS

```

GENE CONE

0

0

CREATED: 811201 180633

PRINTED: 811201 180633

```
53      *                                JZ(LTR1,100)
54      NSECT=4: 1 2 "K2" "K1" 1 "NR" 1
55      *                                LABEL 100
56      *                                JZ(LTR2,200)
57      MOD JOINT="NRH1": NSECT=5: 1 2 "K2" "K1" 1 "NR" 1
58      *                                LABEL 200
59      *                                RETURN
60      *                                ENDELD
61      *(BN)
62      1: "NR1": "BN3": "JT1"
```


VIBRATIONAL MODE.

ID= 1/ 1/ 1

EIGENVALUE= .4030203+04, FREQ= 10.1038 HZ

| JOINT | 1 | 2 | 3 | 4 | 5 | 6 |
|-------|----------|---------|----------|----------|----------|----------|
| 1 | .105+01 | .000 * | -.289+00 | .000 * | -.579-02 | .000 * |
| 2 | .759+00 | .359+00 | -.211+00 | -.203-01 | -.517-02 | -.528-01 |
| 3 | .129-01 | .513+00 | -.458-02 | -.284-01 | -.255-03 | -.736-01 |
| 4 | -.751+00 | .366+00 | .208+00 | -.199-01 | .476-02 | -.514-01 |
| 5 | -.109+01 | .000 * | .304+00 | .000 * | .821-02 | .000 * |
| 6 | .844+00 | .000 * | -.208+00 | .000 * | -.343-02 | .000 * |
| 7 | .610+00 | .291+00 | -.152+00 | -.747-02 | -.259-02 | -.210-01 |
| 8 | .911-02 | .415+00 | -.316-02 | -.106-01 | -.891-04 | -.292-01 |
| 9 | -.605+00 | .296+00 | .150+00 | -.747-02 | .256-02 | -.203-01 |
| 10 | -.873+00 | .000 * | .219+00 | .000 * | .385-02 | .000 * |
| 11 | .600+00 | .000 * | -.108+00 | .000 * | -.454-02 | .000 * |
| 12 | .433+00 | .208+00 | -.795-01 | -.268-02 | -.335-02 | -.993-02 |
| 13 | .510-02 | .296+00 | -.158-02 | -.378-02 | -.768-04 | -.136-01 |
| 14 | -.429+00 | .210+00 | .779-01 | -.267-02 | .329-02 | -.936-02 |
| 15 | -.619+00 | .000 * | .114+00 | .000 * | .483-02 | .000 * |
| 16 | .335+00 | .000 * | .000 * | .000 * | -.583-02 | .000 * |
| 17 | .238+00 | .119+00 | .000 * | -.116-03 | -.427-02 | -.375-02 |
| 18 | .117-02 | .169+00 | .000 * | -.155-03 | -.763-04 | -.522-02 |
| 19 | -.238+00 | .120+00 | .000 * | -.106-03 | .419-02 | -.363-02 |
| 20 | -.338+00 | .000 * | .000 * | .000 * | .612-02 | .000 * |

VIBRATIONAL MODE.

ID= 1/ 1/ 2

EIGENVALUE= .3667824+05, FREQ= 30.4807 HZ

| JOINT | 1 | 2 | 3 | 4 | 5 | 6 |
|-------|----------|----------|----------|----------|----------|----------|
| 1 | .148+00 | .000 * | -.691-01 | .000 * | .164-01 | .000 * |
| 2 | .116-01 | .328-01 | -.393-02 | -.934-02 | .313-03 | -.179-01 |
| 3 | -.147+00 | .486-02 | .698-01 | .104-03 | -.165-01 | .549-03 |
| 4 | -.114-01 | -.277-01 | .386-02 | .937-02 | -.295-03 | .180-01 |
| 5 | .145+00 | .000 * | -.703-01 | .000 * | .167-01 | .000 * |
| 6 | .978+00 | .000 * | -.380+00 | .000 * | .138-01 | .000 * |
| 7 | .358-01 | .213+00 | -.135-01 | -.299-01 | .405-03 | -.606-01 |
| 8 | -.102+01 | .710-02 | .397+00 | .719-03 | -.139-01 | .535-02 |
| 9 | -.344-01 | -.213+00 | .129-01 | .307-01 | -.380-03 | .632-01 |
| 10 | .105+01 | .000 * | -.412+00 | .000 * | .140-01 | .000 * |
| 11 | .101+01 | .000 * | -.355+00 | .000 * | -.632-02 | .000 * |
| 12 | .414-01 | .224+00 | -.150-01 | -.215-01 | -.355-03 | -.399-01 |
| 13 | -.106+01 | .720-02 | .376+00 | -.226-03 | .684-02 | .449-02 |
| 14 | -.396-01 | -.226+00 | .143-01 | .222-01 | .340-03 | .424-01 |
| 15 | .111+01 | .000 * | -.395+00 | .000 * | -.732-02 | .000 * |
| 16 | .189+00 | .000 * | .000 * | .000 * | -.231-01 | .000 * |
| 17 | .518-02 | .575-01 | .000 * | -.258-02 | -.941-03 | -.508-02 |
| 18 | -.191+00 | .215-02 | .000 * | -.241-03 | .241-01 | .110-03 |
| 19 | -.507-02 | -.561-01 | .000 * | .259-02 | .897-03 | .518-02 |
| 20 | .193+00 | .000 * | .000 * | .000 * | -.251-01 | .000 * |

VIBRATIONAL MODE.

ID= 1/ 1/ 3

EIGENVALUE= .9131283+05, FREQ= 48.0935 HZ

| JOINT | 1 | 2 | 3 | 4 | 5 | 6 |
|-------|----------|----------|----------|----------|----------|----------|
| 1 | -.327-01 | .000 * | .153-01 | .000 * | -.111-01 | .000 * |
| 2 | .139-01 | -.362-02 | -.732-02 | .198-02 | .716-02 | .327-02 |
| 3 | .133-01 | .149-02 | -.552-02 | -.193-02 | .118-02 | -.266-02 |
| 4 | -.175-01 | .103-02 | .840-02 | .690-03 | -.818-02 | .377-03 |
| 5 | .132-01 | .000 * | -.729-02 | .000 * | .107-01 | .000 * |
| 6 | -.561+00 | .000 * | .237+00 | .000 * | -.356-01 | .000 * |
| 7 | .360+00 | -.449-01 | -.153+00 | .103-01 | .237-01 | .165-01 |
| 8 | .712-01 | .514-01 | -.286-01 | -.143-01 | .275-02 | -.264-01 |
| 9 | -.422+00 | -.281-01 | .179+00 | .985-02 | -.280-01 | .207-01 |
| 10 | .546+00 | .000 * | -.234+00 | .000 * | .376-01 | .000 * |
| 11 | -.154+01 | .000 * | .593+00 | .000 * | .213-03 | .000 * |
| 12 | .105+01 | -.118+00 | -.404+00 | .231-01 | -.224-03 | .251-01 |
| 13 | .126+00 | .157+00 | -.479-01 | -.330-01 | -.442-03 | -.499-01 |
| 14 | -.124+01 | -.105+00 | .478+00 | .239-01 | .587-03 | .459-01 |
| 15 | .169+01 | .000 * | -.654+00 | .000 * | -.870-03 | .000 * |
| 16 | -.150+00 | .000 * | .000 * | .000 * | .485-01 | .000 * |
| 17 | .100+00 | -.215-01 | .000 * | .340-02 | -.326-01 | .241-02 |
| 18 | .120-01 | .275-01 | .000 * | -.351-02 | -.384-02 | -.339-02 |
| 19 | -.113+00 | -.176-01 | .000 * | .163-02 | .384-01 | .235-02 |
| 20 | .152+00 | .000 * | .000 * | .000 * | -.519-01 | .000 * |

DISPLACEMENTS, MACRO ELEMENT TOP , NREF= 2
 SET= 1, CON= 1, VECTOR= 1
 EIGENVALUE= .4030203+04, FREQ= 10.1038 HZ

| JOINT | 1 | 2 | 3 | 4 | 5 | 6 |
|-------|----------|----------|-----------|-----------|-----------|-----------|
| 1 | .105+01B | .224-07B | -.289+00B | .116-09B | -.579-02B | .000 B |
| 2 | .101+01 | .805-01 | -.279+00 | -.102-01 | -.167-02 | -.193-01 |
| 3 | .961+00 | .157+00 | -.264+00 | -.111-01 | -.337-02 | -.252-01 |
| 4 | .903+00 | .229+00 | -.248+00 | -.109-01 | -.333-02 | -.288-01 |
| 5 | .835+00 | .297+00 | -.231+00 | -.115-01 | -.185-02 | -.338-01 |
| 6 | .759+00B | .359+00B | -.211+00B | -.203-01B | -.517-02B | -.528-01B |
| 7 | .103+01 | -.372-02 | -.284+00 | -.121-01 | -.478-03 | -.281-01 |
| 8 | .977+00 | .750-01 | -.265+00 | -.104-01 | -.253-02 | -.232-01 |
| 9 | .926+00 | .150+00 | -.249+00 | -.999-02 | -.379-02 | -.224-01 |
| 10 | .868+00 | .221+00 | -.233+00 | -.911-02 | -.371-02 | -.227-01 |
| 11 | .803+00 | .287+00 | -.217+00 | -.821-02 | -.254-02 | -.231-01 |
| 12 | .734+00 | .347+00 | -.203+00 | -.596-02 | -.897-04 | -.185-01 |
| 13 | .994+00 | -.281-02 | -.270+00 | -.950-02 | -.265-02 | -.213-01 |
| 14 | .943+00 | .733-01 | -.252+00 | -.927-02 | -.281-02 | -.211-01 |
| 15 | .889+00 | .145+00 | -.234+00 | -.845-02 | -.362-02 | -.196-01 |
| 16 | .832+00 | .213+00 | -.218+00 | -.772-02 | -.354-02 | -.190-01 |
| 17 | .771+00 | .276+00 | -.204+00 | -.660-02 | -.267-02 | -.180-01 |
| 18 | .707+00 | .334+00 | -.190+00 | -.615-02 | -.203-02 | -.182-01 |
| 19 | .950+00 | -.211-02 | -.253+00 | -.763-02 | -.314-02 | -.171-01 |
| 20 | .903+00 | .707-01 | -.235+00 | -.750-02 | -.304-02 | -.172-01 |
| 21 | .851+00 | .140+00 | -.219+00 | -.704-02 | -.363-02 | -.167-01 |
| 22 | .796+00 | .204+00 | -.204+00 | -.632-02 | -.352-02 | -.158-01 |
| 23 | .738+00 | .265+00 | -.190+00 | -.569-02 | -.280-02 | -.153-01 |
| 24 | .675+00 | .320+00 | -.178+00 | -.536-02 | -.232-02 | -.154-01 |
| 25 | .901+00 | -.902-03 | -.232+00 | -.658-02 | -.393-02 | -.150-01 |
| 26 | .859+00 | .683-01 | -.217+00 | -.572-02 | -.313-02 | -.133-01 |
| 27 | .812+00 | .134+00 | -.203+00 | -.560-02 | -.365-02 | -.135-01 |
| 28 | .761+00 | .196+00 | -.190+00 | -.517-02 | -.353-02 | -.132-01 |
| 29 | .704+00 | .253+00 | -.177+00 | -.493-02 | -.281-02 | -.136-01 |
| 30 | .644+00 | .306+00 | -.165+00 | -.404-02 | -.296-02 | -.120-01 |
| 31 | .844+00B | .186-07B | -.208+00B | .873-10B | -.343-02B | .000 B |
| 32 | .817+00 | .651-01 | -.200+00 | -.454-02 | -.324-02 | -.108-01 |
| 33 | .772+00 | .127+00 | -.187+00 | -.471-02 | -.375-02 | -.116-01 |
| 34 | .725+00 | .186+00 | -.175+00 | -.394-02 | -.362-02 | -.103-01 |
| 35 | .675+00 | .241+00 | -.165+00 | -.374-02 | -.292-02 | -.106-01 |
| 36 | .610+00B | .291+00B | -.152+00B | -.747-02B | -.259-02B | -.210-01B |
| 37 | .105+01 | .342-01 | -.293+00 | -.387-02 | -.308-02 | -.984-02 |
| 38 | .101+01 | .116+00 | -.283+00 | -.645-02 | -.212-02 | -.143-01 |
| 39 | .961+00 | .196+00 | -.269+00 | -.934-02 | -.379-02 | -.225-01 |
| 40 | .903+00 | .272+00 | -.253+00 | -.107-01 | -.370-02 | -.274-01 |
| 41 | .835+00 | .343+00 | -.236+00 | -.116-01 | -.235-02 | -.315-01 |
| 42 | .759+00 | .406+00 | -.216+00 | -.150-01 | -.333-02 | -.371-01 |
| 43 | .103+01 | .327-01 | -.286+00 | -.178-01 | -.294-02 | -.249-01 |
| 44 | .977+00 | .111+00 | -.270+00 | -.123-01 | -.219-02 | -.249-01 |
| 45 | .926+00 | .185+00 | -.255+00 | -.103-01 | -.363-02 | -.236-01 |

DISPLACEMENTS, MACRO ELEMENT MID , NREF= 3
 SET= 1, CON= 1, VECTOR= 2
 EIGENVALUE= .3667824+05, FREQ= 30.4807 HZ

| JOINT | 1 | 2 | 3 | 4 | 5 | 6 |
|-------|-----------|----------|-----------|-----------|-----------|-----------|
| 1 | .358-01B | .213+00B | -.135-01B | -.299-01B | .405-03B | -.606-01B |
| 2 | -.201+00 | .206+00 | .720-01 | -.318-01 | .261-02 | -.607-01 |
| 3 | -.432+00 | .181+00 | .160+00 | -.314-01 | .220-02 | -.567-01 |
| 4 | -.647+00 | .139+00 | .243+00 | -.301-01 | .108-02 | -.489-01 |
| 5 | -.842+00 | .809-01 | .322+00 | -.323-01 | -.303-02 | -.354-01 |
| 6 | -.102+01B | .710-02B | .397+00B | .719-03B | -.139-01B | .535-02B |
| 7 | .567-01 | .218+00 | -.275-01 | -.301-01 | .238-02 | -.636-01 |
| 8 | -.179+00 | .213+00 | .632-01 | -.309-01 | .231-02 | -.630-01 |
| 9 | -.411+00 | .190+00 | .151+00 | -.315-01 | .194-02 | -.620-01 |
| 10 | -.638+00 | .149+00 | .239+00 | -.329-01 | .102-02 | -.619-01 |
| 11 | -.863+00 | .900-01 | .328+00 | -.369-01 | -.187-02 | -.651-01 |
| 12 | -.109+01 | .130-01 | .419+00 | -.429-01 | -.171-01 | -.780-01 |
| 13 | .750-01 | .223+00 | -.328-01 | -.266-01 | .107-02 | -.575-01 |
| 14 | -.164+00 | .220+00 | .566-01 | -.267-01 | .185-02 | -.566-01 |
| 15 | -.400+00 | .197+00 | .146+00 | -.272-01 | .153-02 | -.561-01 |
| 16 | -.636+00 | .156+00 | .236+00 | -.287-01 | .556-03 | -.574-01 |
| 17 | -.879+00 | .964-01 | .330+00 | -.315-01 | -.195-02 | -.605-01 |
| 18 | -.113+01 | .171-01 | .430+00 | -.333-01 | -.693-02 | -.606-01 |
| 19 | .768-01 | .225+00 | -.321-01 | -.240-01 | .518-03 | -.524-01 |
| 20 | -.159+00 | .222+00 | .555-01 | -.241-01 | .152-02 | -.527-01 |
| 21 | -.397+00 | .200+00 | .144+00 | -.249-01 | .122-02 | -.539-01 |
| 22 | -.640+00 | .160+00 | .235+00 | -.262-01 | .261-03 | -.559-01 |
| 23 | -.888+00 | .990-01 | .330+00 | -.279-01 | -.182-02 | -.580-01 |
| 24 | -.114+01 | .189-01 | .426+00 | -.291-01 | -.308-02 | -.578-01 |
| 25 | .652-01 | .225+00 | -.255-01 | -.220-01 | -.414-04 | -.468-01 |
| 26 | -.165+00 | .221+00 | .588-01 | -.220-01 | .130-02 | -.480-01 |
| 27 | -.404+00 | .199+00 | .147+00 | -.231-01 | .101-02 | -.511-01 |
| 28 | -.654+00 | .158+00 | .239+00 | -.240-01 | .375-04 | -.532-01 |
| 29 | -.900+00 | .978-01 | .330+00 | -.229-01 | -.201-02 | -.498-01 |
| 30 | -.112+01 | .180-01 | .416+00 | -.254-01 | .222-02 | -.537-01 |
| 31 | .414-01B | .224+00B | -.150-01B | -.215-01B | -.355-03B | -.399-01B |
| 32 | -.177+00 | .218+00 | .641-01 | -.207-01 | .128-02 | -.439-01 |
| 33 | -.419+00 | .195+00 | .153+00 | -.224-01 | .953-03 | -.495-01 |
| 34 | -.677+00 | .151+00 | .248+00 | -.230-01 | -.194-04 | -.514-01 |
| 35 | -.924+00 | .867-01 | .339+00 | -.202-01 | -.191-02 | -.448-01 |
| 36 | -.106+01B | .720-02B | .376+00B | -.226-03B | .684-02B | .449-02B |
| 37 | .355-01 | .318+00 | -.107-01 | -.244-01 | .781-03 | -.613-01 |
| 38 | -.201+00 | .310+00 | .758-01 | -.267-01 | .276-02 | -.613-01 |
| 39 | -.431+00 | .281+00 | .163+00 | -.258-01 | .244-02 | -.587-01 |
| 40 | -.647+00 | .232+00 | .245+00 | -.231-01 | .147-02 | -.526-01 |
| 41 | -.841+00 | .165+00 | .320+00 | -.254-01 | -.255-02 | -.426-01 |
| 42 | -.102+01 | .888-01 | .383+00 | -.582-02 | -.105-01 | -.285-01 |
| 43 | .571-01 | .316+00 | -.229-01 | -.303-01 | .131-02 | -.646-01 |
| 44 | -.179+00 | .311+00 | .661-01 | -.309-01 | .245-02 | -.641-01 |
| 45 | -.412+00 | .287+00 | .154+00 | -.310-01 | .207-02 | -.626-01 |

DISPLACEMENTS, MACRO ELEMENT BOT , NREF= 5
 SET= 1, CON= 1, VECTOR= 3
 EIGENVALUE= .9131283+05, FREQ= 48.0935 HZ

| JOINT | 1 | 2 | 3 | 4 | 5 | 6 |
|-------|-----------|-----------|-----------|-----------|-----------|----------|
| 1 | -.124+01B | -.105+00B | .478+00B | .239-01B | .587-03B | .459-01B |
| 2 | -.633+00 | -.177+00 | .240+00 | .729-01 | .803-02 | .764-01 |
| 3 | -.198-01 | -.202+00 | .108-01 | .652-01 | .320-03 | .831-01 |
| 4 | .584+00 | -.180+00 | -.213+00 | .631-01 | -.102-01 | .771-01 |
| 5 | .115+01 | -.113+00 | -.431+00 | .705-01 | -.173-01 | .575-01 |
| 6 | .169+01B | -.281-07B | -.654+00B | -.145-10B | -.870-03B | .000 B |
| 7 | -.115+01 | -.879-01 | .426+00 | .704-01 | .407-02 | .133+00 |
| 8 | -.556+00 | -.156+00 | .207+00 | .692-01 | .987-02 | .114+00 |
| 9 | -.209-01 | -.179+00 | .108-01 | .670-01 | .589-03 | .979-01 |
| 10 | .480+00 | -.161+00 | -.171+00 | .664-01 | -.104-01 | .952-01 |
| 11 | .986+00 | -.103+00 | -.361+00 | .756-01 | -.194-01 | .106+00 |
| 12 | .153+01 | -.325-02 | -.572+00 | .864-01 | -.563-02 | .129+00 |
| 13 | -.951+00 | -.702-01 | .343+00 | .447-01 | .170-01 | .829-01 |
| 14 | -.466+00 | -.126+00 | .165+00 | .442-01 | .111-01 | .780-01 |
| 15 | -.226-01 | -.146+00 | .103-01 | .420-01 | .863-03 | .671-01 |
| 16 | .381+00 | -.132+00 | -.130+00 | .434-01 | -.103-01 | .645-01 |
| 17 | .806+00 | -.848-01 | -.283+00 | .502-01 | -.204-01 | .711-01 |
| 18 | .126+01 | -.268-02 | -.459+00 | .575-01 | -.228-01 | .717-01 |
| 19 | -.705+00 | -.524-01 | .240+00 | .312-01 | .237-01 | .627-01 |
| 20 | -.343+00 | -.940-01 | .113+00 | .289-01 | .124-01 | .575-01 |
| 21 | -.167-01 | -.108+00 | .640-02 | .263-01 | .126-02 | .493-01 |
| 22 | .281+00 | -.980-01 | -.882-01 | .272-01 | -.105-01 | .477-01 |
| 23 | .594+00 | -.634-01 | -.194+00 | .330-01 | -.216-01 | .533-01 |
| 24 | .933+00 | -.280-02 | -.321+00 | .414-01 | -.317-01 | .564-01 |
| 25 | -.422+00 | -.349-01 | .124+00 | .190-01 | .309-01 | .385-01 |
| 26 | -.198+00 | -.594-01 | .532-01 | .157-01 | .136-01 | .344-01 |
| 27 | .134-03 | -.673-01 | -.832-03 | .135-01 | .158-02 | .293-01 |
| 28 | .179+00 | -.603-01 | -.470-01 | .132-01 | -.106-01 | .273-01 |
| 29 | .360+00 | -.392-01 | -.979-01 | .153-01 | -.226-01 | .296-01 |
| 30 | .560+00 | -.316-02 | -.168+00 | .231-01 | -.413-01 | .330-01 |
| 31 | -.113+00B | -.176-01B | -.269-07B | .163-02B | .384-01B | .235-02B |
| 32 | -.455-01 | -.239-01 | -.794-02 | .242-02 | .143-01 | .247-02 |
| 33 | .202-01 | -.250-01 | -.910-02 | .926-03 | .187-02 | .218-02 |
| 34 | .767-01 | -.210-01 | -.545-02 | .597-03 | -.107-01 | .146-02 |
| 35 | .119+00 | -.125-01 | -.134-02 | .181-02 | -.231-01 | .622-03 |
| 36 | .152+00B | -.253-08B | -.216-15B | -.863-09B | -.519-01B | .000 B |
| 37 | -.124+01 | -.294+00 | .483+00 | .758-02 | .937-02 | .611-01 |
| 38 | -.633+00 | -.366+00 | .252+00 | .508-01 | .722-02 | .698-01 |
| 39 | -.201-01 | -.391+00 | .105-01 | .436-01 | .323-03 | .821-01 |
| 40 | .583+00 | -.363+00 | -.229+00 | .431-01 | -.105-01 | .820-01 |
| 41 | .115+01 | -.284+00 | -.458+00 | .531-01 | -.165-01 | .701-01 |
| 42 | .169+01 | -.168+00 | -.667+00 | -.335-02 | -.120-01 | .482-01 |
| 43 | -.114+01 | -.281+00 | .450+00 | .855-01 | .498-02 | .130+00 |
| 44 | -.556+00 | -.339+00 | .218+00 | .745-01 | .891-02 | .121+00 |
| 45 | -.208-01 | -.340+00 | .107-01 | .690-01 | .481-03 | .103+00 |

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| SEQ | RR | DATE | TIME | E | WORDS | NJ | NI*NJ | T | DATA SET NAME | N3 | N4 |
|-----|------|--------|--------|---|-------|----|-------|----|---------------|------|-----|
| 1 | 17 | 811201 | 181048 | 0 | 18 | 1 | 18 | 0 | JDF1 BTAB | 1 | 8 |
| 2 | -18 | 811201 | 181048 | 0 | 20 | 20 | 20 | 0 | JREF BTAB | 2 | 6 |
| 3 | -19 | 811201 | 181048 | 0 | 12 | 1 | 12 | -1 | ALTR BTAB | 2 | 4 |
| 4 | -20 | 811201 | 181048 | 0 | 20 | 1 | 20 | 0 | JSEQ BTAB | 2 | 17 |
| 5 | -21 | 811201 | 181048 | 0 | 20 | 1 | 20 | 0 | SEQ BTAB | 2 | 170 |
| 6 | 22 | 811201 | 181048 | 0 | 60 | 20 | 60 | -1 | JLOC BTAB | 2 | 5 |
| 7 | 25 | 811201 | 181048 | 0 | 20 | 20 | 20 | 0 | JREF BTAB | 2 | 6 |
| 8 | 26 | 811201 | 181048 | 0 | 20 | 20 | 20 | 0 | CON | 1 | 0 |
| 9 | 27 | 811201 | 181048 | 0 | 60 | 5 | 60 | -1 | ALTR BTAB | 2 | 4 |
| 10 | 30 | 811201 | 181048 | 0 | 180 | 20 | 180 | -1 | QJJT BTAB | 2 | 19 |
| 11 | 37 | 811201 | 181055 | 0 | 20 | 20 | 20 | 0 | CON | 9999 | 0 |
| 12 | 38 | 811201 | 181254 | 0 | 21432 | 47 | 1786 | -1 | RK BTAB | 6 | 0 |
| 13 | 806 | 811201 | 181254 | 0 | 21432 | 47 | 1786 | -1 | RM BTAB | 6 | 0 |
| 14 | 1574 | 811201 | 181302 | 0 | 20 | 20 | 20 | 0 | SEQ BTAB | 2 | 170 |
| 15 | 1575 | 811201 | 181302 | 0 | 20 | 20 | 20 | 0 | JSEQ BTAB | 2 | 17 |
| 16 | 1576 | 811201 | 181306 | 0 | 1792 | 20 | 1792 | 0 | KMAP TOPO | 75 | 10 |
| 17 | 1640 | 811201 | 181306 | 0 | 896 | 1 | 896 | 0 | TAN IMAP | 0 | 0 |
| 18 | 1672 | 811201 | 181306 | 0 | 9 | 9 | 9 | 0 | TAN STAT | 0 | 0 |
| 19 | 1673 | 811201 | 181306 | 0 | 6 | 3 | 6 | 0 | TAN TBCT | 0 | 0 |
| 20 | 1674 | 811201 | 181306 | 0 | 8 | 8 | 8 | 0 | TAN PBCT | 0 | 0 |
| 21 | 1675 | 811201 | 181310 | 0 | 4480 | 20 | 2240 | 2 | KSYS SPAR | 36 | 0 |
| 22 | 1995 | 811201 | 181310 | 0 | 4480 | 20 | 2240 | 1 | MSYS SPAR | 36 | 0 |
| 23 | 2155 | 811201 | 181315 | 0 | 360 | 20 | 120 | -1 | VIBR MODE | 1 | 1 |
| 24 | 2170 | 811201 | 181315 | 0 | 360 | 20 | 120 | -1 | VIBR MMOD | 1 | 1 |
| 25 | 2185 | 811201 | 181315 | 0 | 3 | 1 | 3 | -1 | VIBR EVAL | 1 | 1 |
| 26 | 2186 | 811201 | 181315 | 0 | 12 | 1 | 12 | 0 | VIBR STAT | 1 | 1 |
| 27 | 2187 | 811201 | 181349 | 0 | 360 | 20 | 120 | -1 | SYS JMG | 1 | 1 |

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| SEQ | RR | DATE | TIME | E | WORDS | NJ | NI*NJ | T | DATA SET NAME | N3 | N4 |
|-----|------|--------|--------|---|--------|----|-------|---|---------------|----|----|
| 1 | 17 | 811201 | 180759 | 0 | 97888 | 1 | 19992 | 8 | LIB TOP | 1 | 1 |
| 2 | 3513 | 811201 | 180926 | 0 | 97888 | 1 | 19992 | 8 | LIB MID | 1 | 1 |
| 3 | 7009 | 811201 | 181041 | 0 | 106204 | 1 | 19992 | 8 | LIB BOT | 1 | 1 |

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| SEQ | RR | DATE | TIME | E | WORDS | NJ | NI*NJ | T | Y | DATA SET NAME | N1 | N2 | N3 | N4 |
|-----|-----|--------|--------|---|-------|----|-------|----|-----|---------------|-----|-----|----|----|
| 1 | 17 | 811201 | 181108 | 0 | 1786 | 47 | 1786 | -1 | RK | TOP | 6 | 2 | | |
| 2 | 81 | 811201 | 181119 | 0 | 1786 | 47 | 1786 | -1 | RK | TOP | 6 | 3 | | |
| 3 | 145 | 811201 | 181129 | 0 | 1786 | 47 | 1786 | -1 | RK | TOP | 6 | 4 | | |
| 4 | 209 | 811201 | 181137 | 0 | 1786 | 47 | 1786 | -1 | RK | TOP | 6 | 5 | | |
| 5 | 273 | 811201 | 181153 | 0 | 1786 | 47 | 1786 | -1 | RK | MID | 6 | 2 | | |
| 6 | 337 | 811201 | 181200 | 0 | 1786 | 47 | 1786 | -1 | RK | MID | 6 | 3 | | |
| 7 | 401 | 811201 | 181208 | 0 | 1786 | 47 | 1786 | -1 | RK | MID | 6 | 4 | | |
| 8 | 465 | 811201 | 181215 | 0 | 1786 | 47 | 1786 | -1 | RK | MID | 6 | 5 | | |
| 9 | 529 | 811201 | 181225 | 0 | 1786 | 47 | 1786 | -1 | RK | BOT | 6 | 2 | | |
| 10 | 593 | 811201 | 181233 | 0 | 1786 | 47 | 1786 | -1 | RK | BOT | 6 | 3 | | |
| 11 | 657 | 811201 | 181240 | 0 | 1786 | 47 | 1786 | -1 | RK | BOT | 6 | 4 | | |
| 12 | 721 | 811201 | 181247 | 0 | 1786 | 47 | 1786 | -1 | RK | BOT | 6 | 5 | | |
| 13 | 785 | 811201 | 181253 | 0 | 1 | 1 | 1 | -1 | END | END | 999 | 999 | | |

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| SEQ | RR | DATE | TIME | E | WORDS | NJ | NI*NJ | T | Y | DATA SET NAME | N1 | N2 | N3 | N4 |
|-----|-----|--------|--------|---|-------|----|-------|----|-----|---------------|-----|-----|----|----|
| 1 | 17 | 811201 | 181108 | 0 | 1786 | 47 | 1786 | -1 | RM | TOP | 6 | 2 | | |
| 2 | 81 | 811201 | 181119 | 0 | 1786 | 47 | 1786 | -1 | RM | TOP | 6 | 3 | | |
| 3 | 145 | 811201 | 181129 | 0 | 1786 | 47 | 1786 | -1 | RM | TOP | 6 | 4 | | |
| 4 | 209 | 811201 | 181137 | 0 | 1786 | 47 | 1786 | -1 | RM | TOP | 6 | 5 | | |
| 5 | 273 | 811201 | 181153 | 0 | 1786 | 47 | 1786 | -1 | RM | MID | 6 | 2 | | |
| 6 | 337 | 811201 | 181200 | 0 | 1786 | 47 | 1786 | -1 | RM | MID | 6 | 3 | | |
| 7 | 401 | 811201 | 181208 | 0 | 1786 | 47 | 1786 | -1 | RM | MID | 6 | 4 | | |
| 8 | 465 | 811201 | 181215 | 0 | 1786 | 47 | 1786 | -1 | RM | MID | 6 | 5 | | |
| 9 | 529 | 811201 | 181225 | 0 | 1786 | 47 | 1786 | -1 | RM | BOT | 6 | 2 | | |
| 10 | 593 | 811201 | 181233 | 0 | 1786 | 47 | 1786 | -1 | RM | BOT | 6 | 3 | | |
| 11 | 657 | 811201 | 181240 | 0 | 1786 | 47 | 1786 | -1 | RM | BOT | 6 | 4 | | |
| 12 | 721 | 811201 | 181247 | 0 | 1786 | 47 | 1786 | -1 | RM | BOT | 6 | 5 | | |
| 13 | 785 | 811201 | 181253 | 0 | 1 | 1 | 1 | -1 | END | END | 999 | 999 | | |

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| SEQ | RR | DATE | TIME | E | WORDS | NJ | NI*NJ | T | Y | DATA SET NAME | N1 | N2 | N3 | N4 |
|-----|----|--------|--------|---|-------|----|-------|---|------|---------------|----|----|----|----|
| 1 | 17 | 811201 | 181102 | 0 | 8 | 1 | 8 | 0 | SSBT | TOP | 2 | 0 | | |
| 2 | 18 | 811201 | 181114 | 0 | 8 | 1 | 8 | 0 | SSBT | TOP | 3 | 0 | | |
| 3 | 19 | 811201 | 181126 | 0 | 8 | 1 | 8 | 0 | SSBT | TOP | 4 | 0 | | |
| 4 | 20 | 811201 | 181133 | 0 | 8 | 1 | 8 | 0 | SSBT | TOP | 5 | 0 | | |
| 5 | 21 | 811201 | 181147 | 0 | 8 | 1 | 8 | 0 | SSBT | MID | 2 | 0 | | |
| 6 | 22 | 811201 | 181157 | 0 | 8 | 1 | 8 | 0 | SSBT | MID | 3 | 0 | | |
| 7 | 23 | 811201 | 181204 | 0 | 8 | 1 | 8 | 0 | SSBT | MID | 4 | 0 | | |
| 8 | 24 | 811201 | 181212 | 0 | 8 | 1 | 8 | 0 | SSBT | MID | 5 | 0 | | |
| 9 | 25 | 811201 | 181222 | 0 | 8 | 1 | 8 | 0 | SSBT | BOT | 2 | 0 | | |
| 10 | 26 | 811201 | 181230 | 0 | 8 | 1 | 8 | 0 | SSBT | BOT | 3 | 0 | | |
| 11 | 27 | 811201 | 181237 | 0 | 8 | 1 | 8 | 0 | SSBT | BOT | 4 | 0 | | |
| 12 | 28 | 811201 | 181244 | 0 | 8 | 1 | 8 | 0 | SSBT | BOT | 5 | 0 | | |

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| SEQ | RR | DATE | TIME | E | WORDS | NJ | NI*NJ | T | DATA SET NAME | N3 | N4 |
|-----|-----|--------|--------|---|-------|----|-------|----|---------------|----|----|
| 1 | 17 | 811201 | 181315 | 0 | 3 | 1 | 3 | -1 | VIBR EVAL | 1 | 1 |
| 2 | 18 | 811201 | 181353 | 0 | 1296 | 72 | 432 | -1 | USB TOP | 1 | 2 |
| 3 | 66 | 811201 | 181353 | 0 | 1296 | 72 | 432 | -1 | USB TOP | 1 | 3 |
| 4 | 114 | 811201 | 181353 | 0 | 1296 | 72 | 432 | -1 | USB TOP | 1 | 4 |
| 5 | 162 | 811201 | 181353 | 0 | 1296 | 72 | 432 | -1 | USB TOP | 1 | 5 |
| 6 | 210 | 811201 | 181415 | 0 | 1296 | 72 | 432 | -1 | USB MID | 1 | 2 |
| 7 | 258 | 811201 | 181415 | 0 | 1296 | 72 | 432 | -1 | USB MID | 1 | 3 |
| 8 | 306 | 811201 | 181415 | 0 | 1296 | 72 | 432 | -1 | USB MID | 1 | 4 |
| 9 | 354 | 811201 | 181415 | 0 | 1296 | 72 | 432 | -1 | USB MID | 1 | 5 |
| 10 | 402 | 811201 | 181433 | 0 | 1296 | 72 | 432 | -1 | USB BOT | 1 | 2 |
| 11 | 450 | 811201 | 181433 | 0 | 1296 | 72 | 432 | -1 | USB BOT | 1 | 3 |
| 12 | 498 | 811201 | 181433 | 0 | 1296 | 72 | 432 | -1 | USB BOT | 1 | 4 |
| 13 | 546 | 811201 | 181433 | 0 | 1296 | 72 | 432 | -1 | USB BOT | 1 | 5 |
| 14 | 594 | 811201 | 181452 | 0 | 3 | 1 | 3 | -1 | VIBR HZ | 1 | 1 |

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| SEQ | RR | DATE | TIME | E | WORDS | NJ | NI*NJ | T | DATA SET NAME | N3 | N4 |
|-----|-----|--------|--------|---|-------|----|-------|---|---------------|----|----|
| 1 | 17 | 811201 | 180638 | 0 | 14 | 32 | 448 | 6 | SJC TOP | 2 | 0 |
| 2 | 33 | 811201 | 180638 | 0 | 14 | 32 | 448 | 6 | SJC TOP | 3 | 0 |
| 3 | 49 | 811201 | 180638 | 0 | 14 | 32 | 448 | 6 | SJC TOP | 4 | 0 |
| 4 | 65 | 811201 | 180638 | 0 | 14 | 32 | 448 | 6 | SJC TOP | 5 | 0 |
| 5 | 81 | 811201 | 180638 | 0 | 14 | 32 | 448 | 6 | SJC MID | 2 | 0 |
| 6 | 97 | 811201 | 180638 | 0 | 14 | 32 | 448 | 6 | SJC MID | 3 | 0 |
| 7 | 113 | 811201 | 180638 | 0 | 14 | 32 | 448 | 6 | SJC MID | 4 | 0 |
| 8 | 129 | 811201 | 180638 | 0 | 14 | 32 | 448 | 6 | SJC MID | 5 | 0 |
| 9 | 145 | 811201 | 180638 | 0 | 14 | 32 | 448 | 6 | SJC BOT | 2 | 0 |
| 10 | 161 | 811201 | 180638 | 0 | 14 | 32 | 448 | 6 | SJC BOT | 3 | 0 |
| 11 | 177 | 811201 | 180638 | 0 | 14 | 32 | 448 | 6 | SJC BOT | 4 | 0 |
| 12 | 193 | 811201 | 180638 | 0 | 14 | 32 | 448 | 6 | SJC BOT | 5 | 0 |

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| SEQ | RR | DATE | TIME | E | WORDS | NJ | NI*NJ | T | DATA SET NAME | N3 | N4 |
|-----|-----|--------|--------|---|-------|----|-------|---|---------------|----|----|
| 1 | 17 | 811201 | 180633 | 0 | 868 | 32 | 448 | 6 | GENE CONE | 0 | 0 |
| 2 | 49 | 811201 | 180633 | 0 | 1008 | 32 | 448 | 6 | ME DOC | 2 | 0 |
| 3 | 97 | 811201 | 180637 | 0 | 42 | 32 | 448 | 6 | TOP DATA | 1 | 0 |
| 4 | 113 | 811201 | 180637 | 0 | 42 | 32 | 448 | 6 | MID DATA | 1 | 0 |
| 5 | 129 | 811201 | 180637 | 0 | 42 | 32 | 448 | 6 | BOT DATA | 1 | 0 |
| 6 | 145 | 811201 | 180637 | 0 | 154 | 32 | 448 | 6 | SYS DATA | 0 | 0 |
| 7 | 161 | 811201 | 181451 | 0 | 336 | 3 | 336 | 0 | REGI HOUS | 1 | 1 |

End of Document